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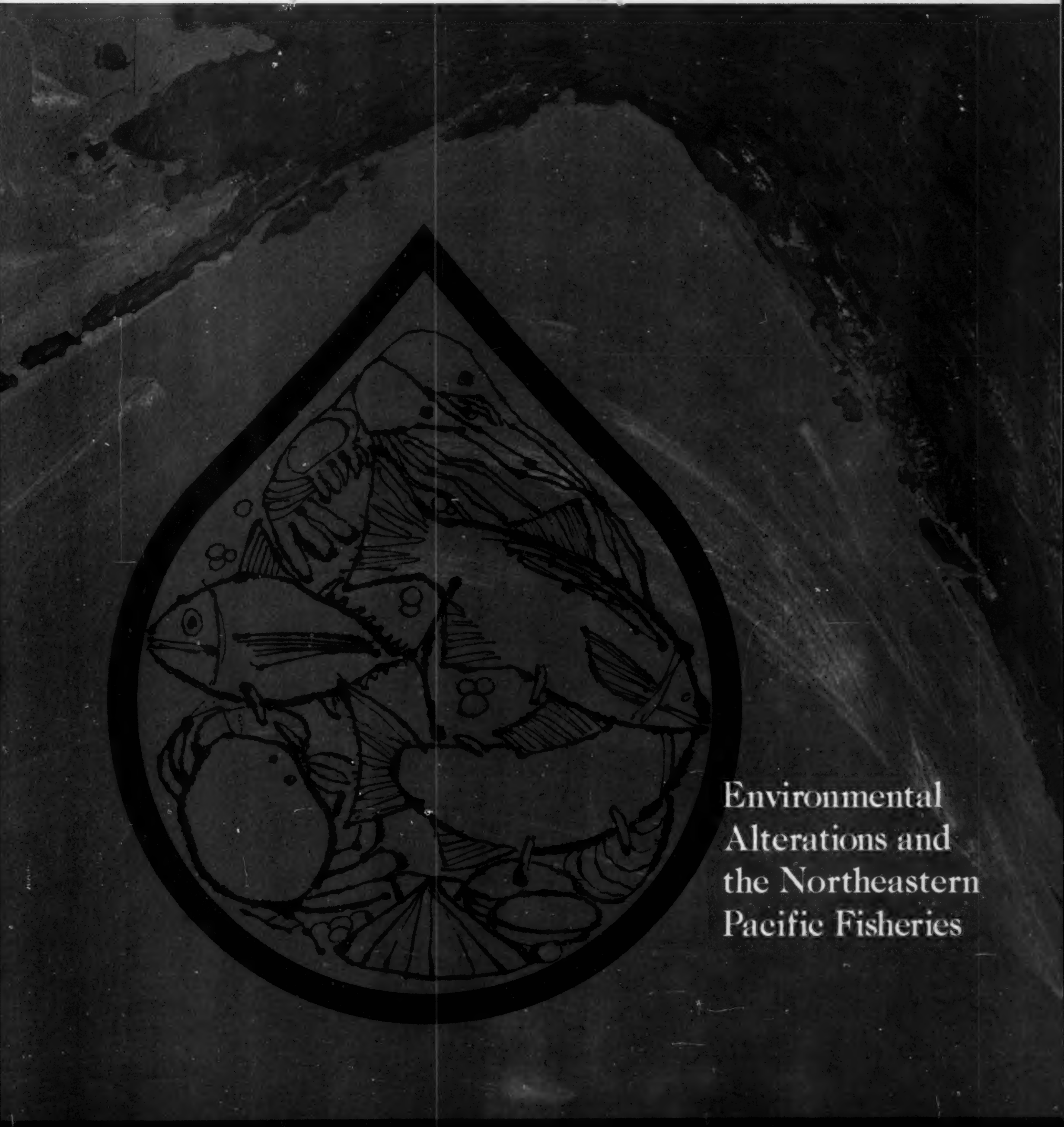

Environmental Alterations and the Northeastern Pacific Fisheries

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Marine Fisheries Review

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Environmental Change and the Northeast Pacific Ocean Fisheries: Introductory Remarks

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Effects upon the biota brought about by alterations in the environment induced by man are discussed in the series of papers in this issue of *Marine Fisheries Review.* Not included in these considerations are changes brought about by harvesting operations in the conduct of a fishery. Thus, depletions of resources from overfishing will not be considered.

The types of changes which are of chief interest here can be placed in three categories. The first of these relates to changes brought about by blocking of waterways, either by dams or by otherwise diverting water in rivers and streams. The second category includes changes which alter temperatures in waters inhabited by aquatic organisms. Water is utilized as a cooling agent in various industrial processes but will be in greater demand by the expanding thermal nuclear power plants. The third category includes operations which result in the transfer of harmful contaminants either through discharge as effluents or from fallout of air pollutants into waters containing aquatic life. This category includes such diverse pollutants as agricultural chemicals, petroleum oil, and municipal sewage effluents.

Whether or not any particular change in the environment from man's activities will have any serious harmful effect will depend, to a considerable extent, upon the species or on the condition of the particular aquatic organism in question. Some species of fish, for example, are exceedingly hardy and can withstand drastic environmental alterations, while others are very delicate and may be harmed when only slight environmental changes take place. Of even greater importance, however, is the stage in the life history of aquatic organisms when they are exposed to altered environmental conditions. Fish at the larval stage, for example, are often exceedingly sensitive and may be killed or otherwise seriously affected at levels of environmental alteration that would go unnoticed by adults of the same species.

Another important factor in increasing sensitivity of aquatic organisms to potentially hazardous environmental change is the presence or absence of other stress conditions. Thus, fish in water of lower than optimum salinity may be seriously affected by other environmental changes, such as the presence of low levels of foreign contaminants that might not be apparent for an unstressed fish of the same species.

Even when, under some set of altered environmental conditions, a fish may be totally unaffected—even lacking any sublethal symptoms—there may be indirect effects if the particular altered environment should be lethal to the feed of the fish. Sometimes plankton, serving as an important source of food, may be much more sensitive to pollutants than some of the fish which feed upon them. Such indirect effects upon feed of aquatic organisms can have important adverse actions upon the organisms by depriving them of needed food supply.

Such problems of interference with the well-being of the organism have been important as factors in the determination of the thriving or depletion of fish populations in various geographical situations for many decades. It is only recently, however, that the serious nature of such potential harm has been fully realized. With a much fuller awareness of these hazards much more attention is being paid toward taking steps which will minimize harmful alterations in the environment.

It is now commonplace in the United States to reach decisions—upon whether to permit specified industrial or other operations—to require that an Environmental Impact Statement (EIS) be filed. Such statements often indicate that the potential for harm is so low as to be tolerable. These are written by experts, having knowledge which may enable them to accurately predict what effect the proposed action may have upon fish or other organisms in the biota.

An Environmental Impact Statement can be useful only if sufficient facts are available to the expert who prepares it to enable him to render a valid opinion. The realization of the potential hazards arising from alterations in the environment has come about so recently that there has been inadequate time for research to establish limits for potentially adverse effects. In many cases the facts needed are either not available at all or are so incomplete as to make the statement one that is based on guesswork as much as on sound knowledge. Much of the research to establish a basis for reaching decisions upon the hazards of man-made environmental changes is still at an early stage. A large part of the past research has exposed fish to levels of pollutants far in excess of what occurs in the natural environment. This procedure is often necessary in preliminary studies because the levels occurring under natural conditions are so low (parts per billion, even sometimes parts per trillion) that procedures have not yet been worked out for measuring such low levels. Yet, when preliminary investigations expose fish to levels of parts per million (perhaps thousands of times as much as occur under natural

environmental circumstances), there is no assurance that the harmful effects that may be found would be present at the lower levels.

With inadequate information upon which to prepare an EIS, the expert must nevertheless come up with some judgment. All too frequently, there is neither a precedent to indicate what harm has resulted in an analogous case nor any scientific data which can be used with confidence to predict what is likely to occur in a particular situation. In such an instance the expert(s) preparing the statement are likely to speculate on theoretical premises, even though no facts are available to support such a theory. Such judgments, based upon efforts to protect the biota when adequate facts are not available, frequently bias the situation to an extent that when the facts later become available, it becomes evident that the precautionary protective measures adopted may have been too restrictive —perhaps unnecessary.

This situation demonstrates the need for two urgent steps. First, much more research is required to show the extent of damage to the biota caused under many different circumstances when environmental alteration occurs. In the second place, it must be realized that it is impossible at our present state of knowledge to adopt permanent regulatory measures or guidelines for protection of the biota against contaminants in the environment and related alterations brought about by increased industrialization. Rather, we must look upon most measures adopted now as provisional, subject to modification to make them more or less restrictive as research facts accumulate.

The following papers prepared by staff members of Northwest Fisheries Center give detailed discussions of some of the man-made environmental changes which are having, or will in the future have, potentially adverse impact upon the fisheries in the northeastern Pacific Ocean.

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MFR PAPER 1218

Pollution in the Northeast Pacific Ocean

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Contamination of the northeast Pacific Ocean is generally thought to be below the level of serious pollution found in areas such as the North Atlantic Ocean and other oceans of the world. This does not mean that no problems exist or that this is an unusual area that has more self-purifying properties than other marine areas. Contamination does exist as evidenced by contaminated estuaries in various coastal areas and by the levels of chlorinated hydrocarbons, such as DDT and polychlorinated biphenyls, in the fat and blubber of marine mammals in the northeast Pacific. These animals obviously have been in contact with persistent contaminants, but whether this contact occurs on the high seas or in coastal waters is unknown.

The relative freedom of the northeast Pacific Ocean from pollution has been an accident of geography and timing. The settlement and industrialization of the area was slower and occurred later than on other U.S. coasts and even now are concentrated in only a relatively small proportion of the coastline. The prevalence of onshore winds and currents and the relatively narrow continental shelf with a sharp dropoff are also important factors. The shallow, cold Bering Sea will require special consideration when industrialization increases in the future. This lack of serious or recognized general pollution emphasizes the need to examine existing contaminants and the factors that may help to indicate if, when, and where problems may be developing. The information reviewed in this report includes research that is generally applicable and not specific to any single geographic area.

Emphasis in this report on pollution is directed toward the use of coastal waters of northwestern North America as a receptacle for man's wastes from domestic, industrial, and agricultural activities, in addition to factors involved in evaluation of effects on the marine life. Attention also is given to the history of attempts to minimize the input from these sources, an evaluation of the success and limitations of these attempts, and a discussion of current actions.

Oregon, Washington, Alaska, and

the Province of British Columbia were developed to utilize their raw materials, and early industrial development was related to these resources. Initial —and still major—industries were logging, mining, fishing, and agriculture. The population in the Northwest increased rapidly in the late 1940's and, in Oregon and Washington, coincided with a shift to manufacturing industries that required the cheap electrical power being generated from the dams on the Columbia River.

Wastes from these activities polluted some waters of Oregon and Washington, where major fish kills occurred in the 1930's. These kills were primarily in areas where pulp mills were discharging untreated waste into bays and estuaries. Other effects had occurred by that time. The oyster industry had deteriorated; logging practices and sewage discharges had damaged Pacific salmon, *Oncorhynchus* spp., spawning streams; saltwater beaches near metropolitan areas were polluted. Because of these conditions, the Oregon Sanitary Commission and the Washington Water Pollution Control Commission were established to eliminate problems in both fresh and salt water. Actions were delayed during World War II, but by the early 1950's, major pulp mills had changed their processes to decrease the amount of organic wastes discharged into the waters, and metropolitan communities began to treat sewage to remove much of the organic material. These actions thus eliminated significant amounts of obvious contamination in the waterways. In the 1960's, industries in urban areas started to discharge wastes into municipal sewer systems. According to Federal law, by 1977 industries must either discharge their wastes into sewer systems or have their own treatment plants.

Emphasis in water pollution control has always been on maintenance of water quality as defined by man rather than from the standpoint of the biota living in the water. This approach was dictated by lack of available knowledge about what is important to aquatic biological communities and to the individual species utilized by man. The results were that visible problems were treated but problems that were less obvious and more difficult to solve were not defined or controlled. An example from the less obvious problems was the slow recognition of the effects from recalcitrant materials, like chlorinated hydrocarbons, that degrade slowly and accumulate in the environment.

Both State and Federal governments have been increasing the restrictions on use of water for discharge of wastes. State laws vary in requirements, but the laws must meet objectives of Federal laws on water quality and pollution control. Amendments to the Federal Water Pollution Control Act were passed in 1972 to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The national goal is to eliminate the discharge of pollutants into navigable waters by 1985, with interim goals to be met earlier, such as treatment of industrial discharges by 1977, secondary treatment of effluents from sewage plants by 1978, and, by 1983, to have water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the nation's waters. This law is a recognition and not a solution of problems of contaminants in our waters.

Technology exists now to permit us to intercept and treat waste discharges, to remove organic material and bacteria from the wastes, and to remove many other substances present in discharges. The problem remains of what should be done about materials not removed by present technology. Furthermore, future decisions may conclude that it may not be worth the cost and energy required to remove all of the environmental inputs from waste discharges, since some inputs may not be detrimental to the environment. In fact, some waste discharges may even be advantageous. Thus, we must be able to determine the types and quantities of materials that can be added to aquatic environments without detriment. If we do not make these determinations, efforts may be wasted on nonessentials. We also might still be adding traces of materials at concentrations that are detrimental to important marine biota, because of limited, and sometimes confusing, knowledge and understanding of the environmental impact from such contaminant materials.

ENVIRONMENTAL FACTORS

The approaches to investigation of the effects of contaminants in the oceans as contrasted to those in the coastal areas are different for several reasons. Work on ocean problems has ordinarily consisted of surveys to learn which contaminants have been transported from land. Little is known about which materials may be changing the marine environment. The routes of transport, whether by the atmosphere, by ocean currents, or by biological means, are of interest but they usually cannot be changed. The detection of contaminants in the ocean is a danger signal, but the principal measure that can be taken is to avoid significantly increasing the levels of contaminants in the environment. This leads to the need to investigate the land-sea and air-sea interfaces where the bulk of the contaminants are introduced and to determine which contaminants are causing problems. We are concerned, therefore, about contamination in coastal areas in relation to the ocean environment as well as about potential deterioration of coastal waters. The coastal environment receives the first and the greatest impact from use of water for waste disposal. Investigations of contaminants in coastal areas must include recognition of all materials that may become widespread contaminants as well as which contaminants are causing immediate problems in the coastal areas.

Although some contaminants introduced into coastal waters reach the open ocean by water transport, most will not build up to significant levels beyond the continental shelf unless the materials are transported by migratory species or in the atmosphere. Well-known examples are substances transported 1) by the atmosphere, such as chlorinated hydrocarbons—DDT and the polychlorinated biphenyls (PCB's), and 2) by man, such as petroleum oil and waste materials discarded from ships.

The rivers in the Northwest must also be taken into account in our consideration of coastal waters because of their importance as spawning areas for salmon, as sources of contaminants, and as critical factors in the physical environment of coastal waters. This is the case not only of estuarine areas,

but also of the influence of rivers at the freshwater-saltwater interfaces in areas such as Puget Sound and along the Oregon and Washington coast affected by the plume of the Columbia River. Also, silt is introduced by the Columbia River and by much smaller streams, especially by the many glacial streams of the area. The silt is deposited when it contacts salt water and is continuously changing the nature of coastal sediments. The amount of freshwater runoff, which has wide fluctuations both seasonally and from year to year, changes environmental conditions and affects salinity, oxygen content, and temperature of coastal inlets. Man should hesitate to add additional problems, particularly from organic pollution, to areas with these naturally changing conditions.

Consideration of the impact of contaminants on marine animals must include the physical, chemical, and biological reactions of the material, often called fate and effects of contaminants. In this field not nearly enough background research has been conducted to furnish a basis to plan programs to answer specific questions about the effects on the animals of projected environmental changes. The complexity of what is a little understood system and the numerous possibilities for action and interactions mean that is very difficult to determine what we should be doing or not doing to our coastal environment. Since the biological communities of the coastal areas are living in a naturally rugged and changing environment, the species have developed the capabilities to adapt to variable conditions. The capabilities or mechanisms that permit species to adapt to new conditions play a major role in determining what and how much change man can introduce into the environment. On the other hand, we still know too little about these mechanisms to establish generalizations or principles that can apply to specific cases and permit accurate predictions of biological effects from different types of contaminants introduced into different environments.

Physical Environment

The dependence of aquatic organisms on their physical environment is well known, but some specific information should be mentioned to give a clearer picture of how contaminants may impinge on that environment.

The water in most of the coastal areas of the northeastern Pacific Ocean contains adequate nutrients and oxygen, the exceptions sometimes being some of the smaller inlets that have low rates of water exchange. Salinity varies in relation to proximity of freshwater flows. The fresh water has a very important role in such an environmental system because of its relation to stratification and currents as well as to effects on salinity.

Many contaminants are deposited in the sediments. These include both heavy insoluble materials that settle soon after introduction into the water and lighter materials that may adsorb to particulate matter and then settle. The physical conditions, the chemical environment, and the biological organisms present will determine what happens to the sedimented material. Possible events after sedimentation of contaminants include the following: 1) the material is bound to the sediments and is at least temporarily removed from the water system; 2) the material is taken up by organisms which then store it or transform it into soluble compounds which leach back into the water; or 3) the material rests on the surface of the sediments and, if large quantitles are added, changes occur in the character of the sediments and thus of the biological communities. The physical nature of sediments and the chemical and biological reactions in the sediments are important factors in determining the ultimate fate of contaminants, e.g., their transformations and their recycling, and in determining the capacity of an area to assimilate contamination.

The water dilutes and fractionates contaminating effluents as well as physically transporting them. Many contaminants that are soluble in fresh water will precipitate in salt water. This characteristic involves a complicated physical process at the interfaces between fresh water and salt water, which are horizontal rather than vertical interfaces in stratified waters. Many of these reactions at the interfaces can be studied on the basis of principles of physical chemistry and are important in determining the introduction of contaminants into the marine system and what plants and animals will come in contact with the contaminants. These reactions at the freshwater-saltwater interfaces result in deposition and buildup of contaminants in two areas, namely—the layer at the interface and the deposition areas in the sediments.

Water parameters that are critical for aquatic organisms are dissolved oxygen, temperature, and salinity. Kinne (1964) reviewed the effects of salinity and temperature on marine animals and Alderdice (1972) proposed methods to evaluate quantitatively the responses of marine poikilotherms to the above environmental parameters. These parameters determine the activity and the metabolism of the animals and influence the effects of many contaminants.

Oxygen Levels

The amount of dissolved oxygen required by the biota is related to the rate of metabolism, which is dependent on the temperature in these cold-blooded animals. The importance of maintaining adequate levels of dissolved oxygen is the reason that pollution control has for many years emphasized the control of the discharge of oxidizable organic material that will react and lower the dissolved oxygen content of the water. Depth and rate of water exchange also affect the levels of oxygen. Anoxic conditions in the Northwest have been reported in bays and inlets, especially during later summer and early fall in years of low water runoff. When the oxygen level is so low that the surface of the sediments becomes anoxic, benthic and epibenthic organisms are killed.

Water for migrating salmon should contain at least 5 ppm oxygen and spawning areas should be at higher levels. Salmon will avoid areas with low oxygen levels when possible and will delay their migration into streams with low oxygen levels until increased flow of water increases the oxygen content. Smith et al. (1972) studied the effects of sublethal levels of oxygen on activity and physiology of coho salmon, *O. kisutch*, and reported that the fish will adjust to some degree through use of anaerobic metabolism for energy. The adjustment to low dissolved oxygen also involved kidney function and

possibly impaired excretory mechanisms of the salmon. Low oxygen levels increase the toxic effects of many contaminants, possibly due to the necessity of the animal to change from its normal aerobic to an anaerobic metabolism. Too little is known about the anaerobic metabolism of fish, however, to predict the interaction between specific contaminants and fish utilizing anaerobic metabolism.

Temperature

Both the range and the optimum temperatures vary for different species. Some species have a broad range of temperature in which they can live, although they may not function very well at the extremes. Salmonid species have a relatively narrow tolerance range. The rate of metabolism of all species increases with an increase in temperature. Specific physiological functions may also have an optimum temperature. Thus, the optimum temperature for production of antibodies in salmon is 15°C (Harrell et al., 1976). This plays an important role in the ability of the animals to resist diseases. Temperature also affects the total environment of the fish. Thus, lower temperatures permit higher levels of dissolved oxygen, and higher temperatures permit an increase in the levels of dissolved contaminants. Temperature levels will affect the toxicological impact of a contaminant by changing the metabolism of the animals. This interaction between temperature and the effects of a contaminant is discussed in the section on Toxicology of Contaminants.

Salinity

Salinity is as important as temperature and oxygen in the evaluation of the effects of contaminants on marine species. This may seem obvious but all too often it is not considered when effects of contaminants in coastal waters are evaluated. Such salinity effects are so important that data from freshwater studies cannot be directly applied to saltwater conditions. Salinity is a specific term that refers to the amount of the dissolved salts by weight. The bulk of the salts in normal sea water consists of a constant ratio of nine ions: sodium, potassium, calcium, magnesium, strontium, chloride, bromide, sulfate, and borate. The salts effectively buffer sea water and can react with many contaminants. Acids and alkalies added to a current of sea water will be neutralized at rates that can be calculated. Some contaminants will form insoluble salts in sea water and settle to the sediments, whereas others may become more soluble.

Marine animals vary in the range of salinity they can tolerate, and the optimum for many species will be different at different stages in their life cycles. An important factor in evaluation of results of bioassays for contaminant effects on marine animals is that two variables are being measured if the animals are in water that is not close to the optimum for the species because salinity levels other than optimum may have as much or more effect than the contaminant on the results of the bioassays.

CONTAMINANTS

As recently as the 1960's, the general practice to minimize contamination of our fresh water was to divert as much of the contaminated effluents as possible directly to salt water on the basis that wastes would be quickly diluted, and the tides and currents would transport them to the open ocean, where it was presumed that effects would be negligible. This practice ignored both the physical and chemical differences among pollutants and the lack of information about their possible effects on biological systems. However, effects from overuse were observed both on the receiving salt water and on the estuarine animals living there, and caution was exercised on the amount of waste added to the coastal waters of the Northwest.

An important use for water presumably will continue to be for disposal of some wastes, and we must be able to evaluate what contaminants can be added with reasonable assurance that their addition will not lead to degradation of important aspects of marine ecosystems. This judgment will require setting priorities, defining important aspects, knowing what contaminants can be added and the levels that can be permitted, and understanding interactions among different contaminants and the biota so that acceptable conditions can be established. Determination of the impact of wastes must include assessment of the combined effects of contaminants from all sources discharged into an area. This is difficult to do because all effluents will vary in composition and the information on composition is never complete.

The number and types of contaminants that enter waters is an almost infinite list and there are many ways to classify them. A basic division is to separate them into the hydrophilic or soluble materials and the hydrophobic or relatively insoluble materials. The contaminants are fractionated in water by their solubility and this separation directs their transport and routes in the environment. Some general characteristics of these two classes are given in Table 1.

The hydrophilic and hydrophobic compounds can be subdivided further into inorganic and organic contaminants. Inorganic materials important in the environment include metal ions and many nitrogen, phosphorus, and sulfur compounds. The organic materials include hydrocarbons, such as those from petroleum oil, and chlorinated hydrocarbons, such as many pesticides

Table 1.—Some characteristics and differences between hydrophilic and hydrophobic toxic compounds.

Hydrophilic	Hydrophobic
Watersoluble.	Relatively insoluble.
Often toxic and lethal but can be diluted or degraded rapidly to nontoxic levels.	Toxicity varies but often degrade slowly either in the environment or in animals and can be carried through various trophic levels.
Usually act via respiratory system and amount in water is critical.	Usually transported via food, although in some instances may be introduced via water. In these instances, the amount in the food usually can be orders of magnitude greater than in water before biological effects are noted.
Often catastrophic and animals have no chance to adapt.	Many animals adapt to presence and in 1 or 2 generations resistant populations may be built up.
Removal of source usually removed problem and repopulation depends on recruitment from adjacent communities. Exception: the contaminant that adsorbs to particulate matter is deposited in sediments and may be later recycled into the water.	Removal of source does not remove contaminant problem because of the slow degradation. Length of time necessary involves a combination of chemical and physical processes and of biological or microbiological degradation. Toxicity of the altered and degraded products is also important.

and the PCB's. Interactions between the inorganic and organic materials may transform insoluble to soluble compounds. Thus an insoluble zinc salt, which cannot be used as a nutrient, may bind with organic material by a process known as chelation and, changed to soluble material, becomes an available nutrient. Conversely, the binding between inorganic metals and organic materials may precipitate some metal contaminants and remove them from the water through sedimentation. The reactions of the insoluble compounds after they settle is then dependent on the environmental conditions and biota of the sediments.

Many soluble organic compounds undergo chemical and biological oxidation and add nutrients such as carbon, nitrogen, and phosphorus. They are potential pollutants when their concentration is exceedingly high and they are not rapidly diluted and dispersed. In this case the biological and chemical oxidations may reduce the oxygen level of receiving waters to levels dangerous to the aquatic communities in the area, especially in areas or during seasons with slow water exchange. If nutrients are present at too high levels, they may stimulate undesirable growth such as algae blooms and organisms forming slime. The control of water pollution in the past has been based primarily on removal of excess organic materials from sewage and industrial effluents.

Environmental effects from relatively insoluble compounds on the other hand usually are not as obvious. Many of these materials are slowly degradable and persistent contaminants that accumulate, circulate through the food web, and cause slow, chronic changes. These characteristics make insoluble organic contaminants of particular concern because the effects often are not noted until changes are drastic and possibly irreversible.

The interactions that occur between contaminants and naturally occurring compounds play an important role in potential biological effects, in degradation, and in transformations of the contaminants. These reactions affect the solubility and the toxicity of the compounds and also have an effect on potential biological transformations. Excellent reviews are available on physical and chemical reactions of organic compounds and their degradation by microbial, chemical, and photochemical systems in aquatic environments (Faust and Hunter, 1971) and on equilibria in natural waters (Stumm and Morgan, 1970).

Physical Transport and Distribution of Contaminants

Currents transport soluble contaminants, which tend to be distributed by convective mass transfer. Thus, the contaminants can enter the estuarine system via freshwater runoff. Many will be transported along with the freshwater layer, which is lighter and warmer than the salt water and will have an overall movement to the sea. The system is more complicated than this simplified description since the layers are not definitive and considerable mixing occurs. Many of the compounds soluble in fresh water are insoluble in salt water. Soluble compounds also adhere to particulate matter. In both of these cases transport of the contaminant will then be that described for insoluble material.

The insoluble materials are particles and their transport and distribution is determined by particle size and density as well as movement of water. The particles present will be not only from contaminants but also from natural sources, such as clays, metal compounds, organic detritus, and living microorganisms. Stumm and Morgan (1970) have applied principles of colloidal and surface chemistry to explain and understand the reactions that occur at the solid-solution interfaces of the particulate matter and the water.

Movement of particles is influenced by differences in salinity and by the gradient in electrolyte concentration between the outgoing upper layer of fresh water and the incoming lower layer of salt water. As particles sink, the salt water essentially retains them as the upper layer goes out to sea. Some of the material also accumulates at freshwater-saltwater interfaces. As the insoluble material enters salt water, electrolytes change the settling rate, which is faster for many materials in salt water than in fresh water. Thus, some particles settle, are removed from the water column, and become part of the sediments. Other particles will remain suspended in the salt water but are retained in the water column of the estuary. The above physical processes cause accumulation of many of the materials with the result that concentrations of many substances are higher in estuaries than in the open sea. A diagram of the physical fractionation of effluents is shown in Figure 1. It must be remembered that important as this process is, two other basic types of processes, biological and atmospheric, are also transporting and distributing contaminants.

Toxicology of Contaminants

Two questions that must be answered are how much and at what rate can a potentially toxic material be added to a marine system without causing adverse effects on the biota?

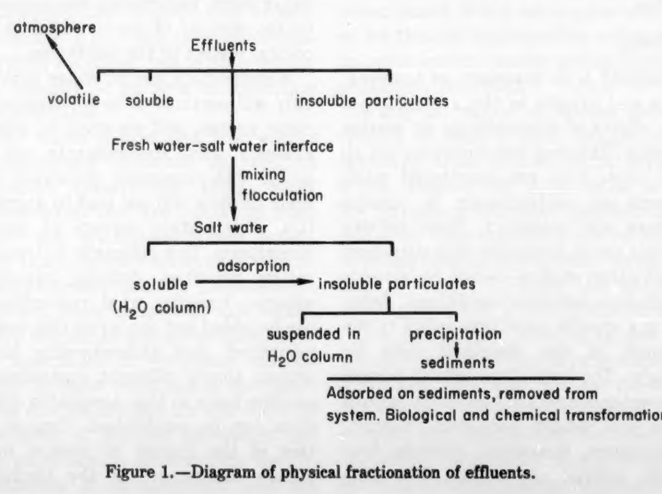

Figure 1.—Diagram of physical fractionation of effluents.

The answers will vary from one place to another depending on environmental conditions such as temperature, pH, salinity, rate of dilution by water movement, and the nature of other materials that are added to the same area. The physical and chemical environment of the area influences the reactions of the flora and fauna to the added material, the reactions and the fate of the contaminant, as well as the reaction between the contaminant and the plants and animals. Nevertheless, if we are ever going to predict the fate and biological effects of contaminants added to the environment, we must be able to apply some general principles and to make recommendations about safety or hazards to the aquatic environment when new industries plan to use water in an area, when decisions are made to minimize effluents from exisitng sources, and particularly when new compounds enter common domestic or industrial wastes in the future.

Contaminants can be characterized by the type of biological responses they cause. These responses may result from acute toxic symptoms that can rapidly kill animals; but if the toxic material is eliminated from the environment, the affected area can quickly recover and repopulation occurs. Short-term sublethal responses may affect behavioral and physiological functions of the biota and may result in indirect or direct death of the animals by making it more difficult for them to avoid predators, to obtain food, or to resist infectious diseases. Finally, long-term sublethal responses may affect populations by their effects on reproduction, such as a decrease in the quantity of fertile eggs, an increase in the time for hatching of eggs, and an increase in the number of abnormal (mutagenic) offspring from eggs that are hatched. Potentially dangerous long-term sublethal effects also result from compounds, such as the chlorinated hydrocarbons, that degrade slowly and the environmental amount continues to increase to a level that becomes dangerous to the biota, even though the incremental amounts added are below toxic levels.

Acute Lethal Effects

Until comparatively recently, much of the available information in the literature has related to acute lethal effects of compounds on fish and shellfish. Such effects have generally been measured on the basis of the death of one-half the animals under specific conditions, i.e., determining the LC_{50}, the concentration of a chemical in the water that will kill half of the animals in a specified time; or LT_{50}, the time required to kill half of the animals at a specified concentration. The data obtained can be useful if the limitations of the results are recognized and if the conclusions and interpolations that are made are not broader than are warranted from experimental limitations. One way to use the data is to apply mathematical equations that include factors for the detoxification of the specific contaminant by the animal and for the susceptibility of the species (Wilber, 1969).

Brown (1973) has summarized concepts of toxicology that apply to toxicological studies on the effects of contaminants on fish. These concepts are basic to evaluation of the conflicting information in reports on the toxic effects of contaminants. In addition to the confusion resulting from conflicting data and conclusions, three important aspects are rarely included in reports on lethal concentrations of contaminants. First, the condition, behavior, and recovery of the 50 percent that remain alive from LC_{50} experiments is usually ignored. The second neglected aspect is the overall response of the animals prior to death and the length of time before the first toxic symptoms are noted. The third is the autopsy report giving the immediate cause of death or lesions that may occur. Such information from lethal studies would help to identify both potential problems from effluents and specific contaminants and their toxic actions on test animals. Such information also could help to suggest possible problems with other species.

Many acute reactions on fish are related to interference with the respiratory mechanisms—whether by removal of oxygen from the water, or by damaging or coating gill tissue and thus preventing transfer of oxygen from the water to the blood stream. The effect on respiration is the reason that contaminants, such as DDT, will be lethal to fish and shellfish at the parts-per-billion level if they are in the water but will have little or no apparent effect at the parts-per-million level if introduced to the animals in food and go through the digestive process. This also illustrates an important toxicological concept: that the method of administration of a contaminant will alter results of tests and will determine both lethal levels and toxic effects of the compounds.

A brief mention should be made about some of the problems that exist in interpretation of data on lethal concentrations of pollutants. The aquatic animals, with the exception of marine mammals, are poikilotherms or cold-blooded creatures with body temperatures dependent on their environment; higher temperatures increase the rate of body metabolism and increase demand for oxygen. This temperature dependence can alter the results of toxicological studies depending on the design of the experiment. When, as is often the case, the experiments are of short duration and involve high concentrations of a contaminant, the animal will not have time to detoxify the contaminant. In this case, temperature will show a direct effect on toxicity and the contaminant will be classified as more toxic at the higher temperatures. On the other hand, if lower, more realistic, concentrations are used, the animal will have time to respond to the contaminant and his biochemical defense mechanisms may act to transform or store the contaminant and possibly render it biologically inactive. In this latter case, higher temperatures within the animal's tolerance range will increase the rate of metabolism and permit the animal to detoxify the contaminant at a greater rate. Under these conditions, the same contaminant would be classified as more toxic at lower temperatures. This instance also illustrates another important toxicological concept: that the dose level of a contaminant will alter results from bioassays.

The defense mechanisms mentioned above will affect other interpretations. for example, if two species are being compared, species one may show a greater sensitivity to the toxicant if the exposure is for a short time period. If

the exposure time is extended, however, species two may not have less capability than species one to develop defense mechanisms. In the second instance the toxicity response curves will reverse, and the contaminant will be much more hazardous to species two.

Chronic Sublethal Effects

Sublethal effects of contaminants can be defined as manifestations of physiological, functional, biochemical, or behavioral change or impairment that do not directly kill individuals but do affect the ability of a species to survive. This definition includes such factors as disorientation, change in growth rate, metabolism, reproduction, disease resistance, change in food supply, ability to react to stress, and change in physiological parameters. Sublethal effects may or may not be harmful to survival of a species. When the effects are harmful they can be more dangerous to survival of the species than lethal effects because the species may have suffered irreparable damage before there is realization that the species has been damaged. Furthermore, knowledge of the sublethal effects of contaminants on species is required before the safety or hazard of a contaminant can be established. Information on sublethal effects is of special importance for those persistent contaminants that degrade slowly and thus may increase in the environment and in the food web. Until recently, very little work was done on chronic sublethal effects of contaminants on aquatic animals. Progress in this area is hampered by a lack of knowledge about many of the normal physiological and biochemical mechanisms and functions in cold-blooded animals. Less work has been done with marine species than with freshwater species because of the limited number of saltwater facilities available for such work. Nevertheless, work has started and this will be an area to watch in the future to learn what factors are critical for marine species and to define when problems may be developing in the marine environment.

EFFECTS OF POLLUTANTS ON MARINE LIFE

Pollutants can be broadly categorized by the type of reactions by which they affect marine life. These broad categories are chemical reactions, such as those associated with poisons like arsenic and cyanide; physical reactions, such as those caused by silt and other particulate matter, temperature changes, high or low salinity levels; and biological reactions, such as those associated with diseases (viruses and bacteria).

A pollutant may be more aptly regarded as a toxicant rather than a poison, which usually has the connotation of causing death. Thus, a toxicant may exert its effects and produce either a long-term or short-term nonlethal effect, which is either sublethal chronic or sublethal acute toxicity, respectively. The application of these definitions to the situation for a particular toxic compound can be quite arbitrary, because both concentration of the toxicant and time for the reaction will determine the biological effects. A high concentration of toxicant for a short time may result in death, while a low concentration for a long time may result in the fish being able to adapt to the presence of the toxicant. Dose-time relationships cannot be be interpolated except for a very small range.

The interrelationships involved with pollution and biological systems can be diagrammatically represented (Fig. 2). The biological effects of a foreign substance from pollution is influenced by the stress of variable environmental conditions, the nature of the foreign substance, such as chemical structure of the pollutant, and the dose of the compound in the body of the affected organisms and time of exposure. Conditions of the environment affect the physical and chemical states of pollution substances, such as degree of solubility in water, adsorption on particulate matter, and ionic conditions of mineral substances. The concentration of toxic substances from pollution in aquatic environments also depends on the physiochemical nature of the environment, such as available particulate matter for adsorption, precipitation as solids, and diffusion characteristics of bodies of water, as well as quantities of the substances entering the environment and their rates of entry. The overall pattern of interrelationships is highly complex in a real sense.

Short-Term Effects

The most obvious and severe forms of activity of a toxicant from pollution are those which result in death of marine life after relatively short exposure. A pollution toxicant, in this instance, produces acute lethal effects, with death resulting from a variety of reasons or factors.

Physical interaction of certain chemical substances and particulate matter with gill surfaces of fish can cause suffocation and death. Chemical products, such as synthetic polymers, and natural substances, such as tar globules

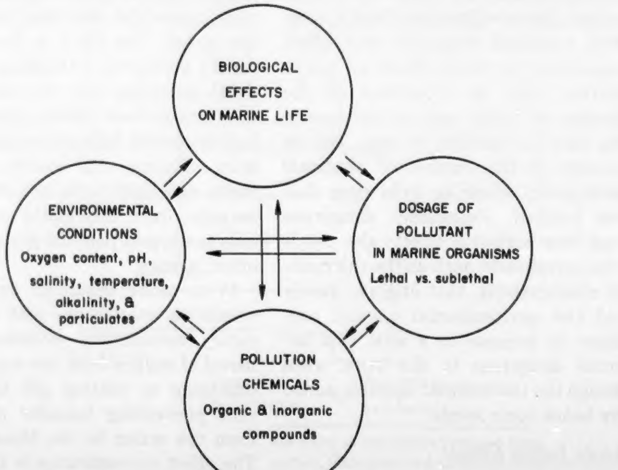

Figure 2.—Interrelationships of aquatic pollution, environmental conditions, and marine biological activities.

and heavy oils from petroleum, can form barriers to oxygen by adhering to gill surfaces. Finely divided particulate matter, like that found in soil silts and mineral or clay sediments, can also adhere to gill surfaces. These products and substances, if in great abundance in an aquatic environment, can overcome the natural cleaning action of mucus-secreting cells in gill epithelia, thereby barring passage of oxygen. Some compounds cause damage to gill rakers and thus cause abnormal respiration.

The gills of fish are the main interceptors of pollutants dissolved in water. Because of the relationship of dissolved pollutants to gills, the biological effects of the pollutants in marine animals may be complex and very difficult to determine. In addition to the physical interactions of pollutants with the gills, chemical reactions also occur. A pollutant may dissolve in the mucus on the gill surfaces and produce a reaction product, which may render the gill function inoperable. Other pollutants, because of peculiar properties, may be easily transported through the gill membranes and into the blood stream. The rate of entry of a pollutant into a fish by this mode is probably faster than any other natural mode of entry; therefore, a fish may concentrate larger amounts in its body tissues from lower environmental levels than it would if the pollutant entered via feeding during a comparable time interval.

Fish vary in their reactions to turbid conditions. Some freshwater fishes can tolerate very turbid conditions, e.g., 100,000 ppm sediment levels, whereas other marine organisms are very sensitive. Adult fish are comparatively tolerant of suspended mineral particles, although abrasion of gills and skin occurs. Eggs, fish larvae, and aquatic insects are not so tolerant. Rainbow trout, *Salmo gairdneri*, can tolerate 30 ppm silt, but incur mortality from 90 ppm. Shellfishes, which are filter feeders, are quite susceptible to the action of silt. In heavy suspensions of mineral particles, the feeding process of oysters can be inhibited completely. Highly turbid water can also block light and reduce the level of photosynthesis.

Contaminants can have a variety of lethal effects. Some chemicals produce paralysis, which can lead to secondary effects such as failure of respiratory function, gastrointestinal dysfunction, and failure of kidney, heart, and general vital organ functions. Aside from these failures, paralysis and even partially impaired mobility can increase susceptibility to predation. Some chemicals acting on the nervous system of fish might produce harm to vital organs and functions, thereby altering normal behavioral patterns essential for survival. Chemicals, such as calcium, may alter the capacity of a fish to properly adjust salt balances in blood and tissue cell components, thus upsetting the vital movement of body-building substances and substances from breakdown of nutritional components for energy. Permeability of cellular membranes is vital to life processes, and it is alterable by calcium salts. Other heavy metal salts may also react with membranes.

Some heavy metals such as iron and zinc are required to sustain life; however, when these and other metals are in solution in excessive amounts, a variety of abnormal effects can arise in the fish. The effects may become lethal if the fish cannot rid themselves of the heavy metals. Young Atlantic salmon, *Salmo salar*, have been found sensitive to soluble inorganic copper and zinc, with an incipient lethal concentration of 48 parts per billion (ppb) of copper sulfate and 600 ppb zinc sulfate in the water. If copper and zinc are present together, young salmon die much faster than if they were in contact with water containing either metal salt separately (Sprague, 1964). This illustrates the yet to be discussed phenomenon of synergism, where fish can be subjected to effects of several contaminants simultaneously. Shellfishes are also very sensitive to dissolved zinc and copper. Dissolved cadmium and organic mercury are among the more toxic metals toward marine fishes. There are other related effects of these contaminants in the environment where our knowledge is very limited.

Organic chemical pollutants, which can enter fish through the food web and be carried in the lipid components of the body, can potentially exert a variety of actions on the numerous biochemical entities in fish (Johnson, 1968; Grant and Schoettger, 1972). For instance, an aquatic environmental substance may antagonize a hormonal system in fish, with an attendant wide range of consequences, several of which could produce death. Hormones regulate the water balance in fish tissues; hormones may regulate urine flow and other vital processes that rely on water balance. Water balance, for example, may affect vital tissue and cellular salt balances by indirect action or by dysfunction of the fish endocrine system. The endocrine system and its activity are related to metabolism, which in turn is affected. Although grossly oversimplified, these examples illustrate the kinds of interactions that are involved in the highly complex nature of the biochemical workings of fish, once organic pollution substances begin to exert their effects.

Another short-term effect of contaminants is related to problems of survival of early life stages of marine organisms, such as sac fry and shellfish larvae. Research on the effects of an insecticide, dieldrin, in sea water on the development of crab larvae has shown that survival was not affected during the first crab stage, but there were 15-27 percent higher mortalities during development to the postlarval stage compared to controls (Epifanio, 1971). Also, results of experiments on an insecticide, DDT, with trout and guppy showed that there was eventual mortality of developing larvae, generally at the sac fry stage when the last remnant of yolk was being absorbed (King, 1962; Macek, 1968).

Some of the very vital areas of the biochemistry of fish, wherein toxicants could exert irreparable damage, include the energy utilization systems, body building processes, and processes of elimination of waste products from the energy utilization and body building processes. The operation and chemistry of the functions and processes associated with body energy, body building, and waste elimination are not completely understood, but pollution toxicants that come in contact and can react with any of the essential biochemical intermediates of these processes potentially can produce an effect on the physiology and behavior of the fish. If such reactions occur, the next step would be to show whether the

effect is significant for prediction of harm or damage to the fish.

Nature has provided, in many instances, for alternatives in natural processes in the event that failure occurs in another process or function. All is not known about the natural processes and functions occurring in bodily systems of fish; therefore, to assess the true biochemical and biological impact of a pollutant chemical upon marine life is often difficult, laborious, long-term, and highly specialized.

Long-Term Effects

Sublethal effects of contaminants on marine life are often insidious and difficult to recognize; yet these effects may produce widespread damage to communities of biota. Sublethal effects may be either direct or indirect, with the indirect effects often more difficult to measure than direct effects, because of the long time needed for positive observations of the indirect or secondary effects.

In discussing the short-term effects above, the possibility was mentioned that direct interactions of toxicants with the fish nervous system can lead to indirect effects on the function of muscles of fish and thus decrease mobility. Although this is a sublethal effect, this situation leads to a secondary lethal effect in that the toxicant renders the creature easy prey to predators.

Another kind of long-term, indirect effect is a decrease in the viability of marine organisms to reproduce. Here, too, no lethal effects are observed on a primary population, but abnormal patterns of numbers of progeny, low rates of development or growth, and deformities of body structures can be caused by certain toxic substances. The viability of species may be affected by alterations in bodily processes for sperm production and the ability of eggs to become fertile. Toxic substances can be transmitted by progenitors and become endogenous to the eggs. In this way, lipid soluble toxicants can be present in the larvae and the very early stages of development of marine organisms (Johnson, 1968).

There is evidence for both long-term lethal and nonlethal effects that can occur in the progeny of fish that have had prior exposure to a toxicant. Where all parents of three generations of laboratory-reared fish were exposed to an insecticide, the first and third surviving progeny (F_1 and F_3 generations, respectively) tended to be less sensitive to DDT than the corresponding unexposed "control" progeny, whereas the second generation fish (F_2 generation) was more sensitive than its control generation (Holland and Coppage, 1970). Deaths occurred in each generation group, but greater percentages died in the more sensitive F_2 generation. Much more work along similar lines is needed for people to understand what the effects of contaminants might be to fish in the wild over many generations. The indications are that the early stages of life, as suggested before, are more susceptible to certain contaminants than the more resistant adult forms of marine life. Moreover, little is known about possible selective actions of the many types of chemical pollutants and other contaminants leading to this phenomenon.

An important direct sublethal effect of a toxicant deals with the phenomenon of "homing" in anadromous fishes. The ability of the fish to sense the proper direction of migration or to locate its home stream, when returning from years in the open ocean, can conceivably be impaired and perhaps totally limited by reactions due to localized environmental pollution. Because the exact processes of homing in these fish are not yet well understood, the ability of researchers to pinpoint evidence for direct toxic effects on the essential aspects of the homing process is difficult.

Some pollution toxicants may cause inhibition of growth rates of maturing fish. Such sublethal effects due to diminished natural food sources (an indirect exogenous environmental effect) or simply poor food utilization (an indirect endogenous effect) can restrict growth of organisms. This kind of biological effect of pollution could have disastrous economic effects on a commercial fishery if allowed to continue unabated.

Another potential long-term sublethal effect deals with the question of disease resistance of fish. What effect could a chemical pollutant have on lowering the resistance, for example, towards a viral infection in a community of flatfish? An increase in the incidence of tumors in flatfish in the San Francisco Bay region has been suspected of being caused by virus; the incidence was also suspected to be pollution oriented (Cooper and Keller, 1969). The bacteria *Vibrio anguillarum*, which causes vibriosis in fish, has been diagnosed as the cause of deaths of salmon raised in saltwater pens in Puget Sound, Wash. (Novotny, 1975; Harrell et al., 1976). It is not known whether or not pollutants play a role in such incidents. The widely publicized environmental pollutants, PCB's, were reported to reduce disease resistance in ducks. Evidence is found for the impairment of immunological processes and disease resistance in higher animals, but little definitive work of this kind has been done with fish.

Additional Considerations

Migratory marine organisms often are forced to undergo particular natural physiological adjustments and adaptations. A short-term adjustment is associated with diel periodicity, which can influence certain physiological processes like those related to day-to-night and night-to-day adjustments. These short-term adjustments in an organism's body are referred to as acclimatization. A much longer adjustment phenomenon in fishes relates to those that may occur once or perhaps only a few times during a life span. This latter adjustment is referred to as adaptation and involves such physiological adjustments as related to saltwater-to-freshwater transitions or cold-to-warm water transitions (temperature adaptation). Both acclimatization and adaptation pose physiological effects and stresses in marine organisms. The interactions of pollution toxicants with the various physiological processes in marine creatures could possibly influence the rates of acclimatization and adaptation. If these rates deviate significantly from the normal rates of adjustment, then potential harm may be incurred in the life processes of the creatures involved.

A third type of adjustment made by fishes, and marine organisms in general, can be called genetic adaptation. This type was alluded to, above, in

discussing effects on viability of the organisms. Experimental evidence on freshwater species has demonstrated what could be regarded as induced genetic adaptation, i.e., the progeny of fishes exposed to sublethal levels of a toxicant are more resistant to lethal levels than were their progenitors at the same life stages. This was shown from studies on the effects of DDT insecticide on guppies (King, 1962) and trout (Macek, 1968).

The molecular structure of chemicals within a class can vary, causing different concentrations of the compounds in different tissues and organs of fish. Such variation in chemical structures are found in gross mixtures of industrial products like PCB's, petroleum hydrocarbons, and synthetic polymers. Polychlorinated biphenyls were found to accumulate selectively in various tissues of coho salmon; the accumulation was dependent on the degree of chlorination on the biphenyl molecules (Gruger et al., 1975). A similar selective accumulation may be found for polycyclic aromatic hydrocarbons from petroleum products, although in this case metabolic reactions may play a role in their elimination.

An extremely important concept in assessment of toxicant effects is that of synergism (Weiss, 1959; O'Brien, 1967). An example was mentioned above. A definition of synergism is the "cooperative action of discrete agencies in such a manner that the total effect is greater than the sum of the effects taken independently." There are numerous examples of synergistic action of one chemical compound with another in biochemical systems. When determining the biological effects of pollution compounds, it is important to include the additional consideration that other compounds, either natural or foreign, can react with the toxicant and reduce its effective concentration and thus produce a corresponding decrease in toxic symptoms. The potential for synergistic activity of pollutants is great in highly industrial as well as in mixed industrial and agricultural areas, where a multitude of different pollutants are apt to be present in the aquatic environments.

In contrast to synergistic activities, the phenomenon of antagonism is important as well. Antagonism is the opposition in physiological action, especially in relation to the interaction of two or more substances, such that the action of any one substance on living systems is modified. This is an instance where, for example, the total effect of pollution toxicants is less than the sum of the individual effects of the toxicants when determined independently.

To provocatively illustrate how antagonism could operate in marine life, we can consider the following possibility: Two fish of the same species, one containing a particular insecticide and the other free of the insecticide, migrate into an estuary containing 100 ppb of certain dissolved residues of petroleum oil products. The residues of oil products find their way into the tissues and cells of the two fish and interact with the physiological processes. In one fish, these processes are already affected by the insecticide. The fish containing the insecticide is apparently healthy, and an analysis of its body tissues shows a maximum of one ppm of residues of the oil products. The fish that does not contain the insecticide appears to be in poor health and perhaps near death, and analysis of its tissues shows a maximum of 100 ppm of the residues. The insecticide could have exerted an antagonistic effect on the activity of the petroleum residues, resulting in a protective action with no apparent effect on health. Without the presence of the insecticide in the body, the fish was severely affected. Another clue in this illustration that the insecticide is antagonistic is that the fish had less oil residues than the fish free of insecticide. An explanation of the effect could be that particular defensive biochemical processes had been activated to deal with the presence of the insecticide and at the same time are able to interact with the petroleum residues and cause their catabolism. Such activated or induced biochemical processes are commonly observed in studies of drug and insecticide actions (Mayer et al., 1970; LaDu et al., 1971).

The role of lipids, or body fats, in modifying the effects of pollution chemicals appears to be an important part of the physiological processes that take place in marine organisms. Many pollutants that are lipid soluble are expected to be located in the body where lipids are also found (Holden, 1962; Johnson, 1968). There are aspects of the role of lipids in such a phenomenon, however, that are not clearly understood. Just because a pollutant is found in a marine organism, it is not necessarily true that there is or will be a toxicological problem. Fish can contain lipid soluble contaminants, whose activities are influenced by their presence in lipid deposits. For example, fish have been shown to contain high concentrations of DDT and its metabolites in lipid deposits without obvious effects. Fatty fish may have quite different problems, compared to lean fish, for the same level of a contaminant in the environment.

Some research has shown that there is either no direct relation or a poorly correlated relation between the lipid content and the concentration of organochlorine compounds in fish tissues and organs. It was suggested that a substance other than lipid has a high affinity for those organochlorine compounds (Grzenda et al., 1971). Perhaps the substance with a high affinity for lipid soluble pollutants is lipoprotein, whose role is little understood for fish. The mode of transport of such pollutants in fish is a problem of current research interest, and the association of the lipid soluble compounds to the lipophilic moieties of natural biochemical components is an important part of that problem.

Another aspect of the effects of compounds from pollution on fish is related to a correlation of prior exposures of the compounds to fish with the establishment of "susceptible" and "resistant" strains of fish. This phenomenon may not necessarily be genetic in nature, because sometimes there are not long-lasting or multiple generation effects. One argument used to explain susceptible fish is that the fish may possess nontoxic, low concentrations of toxic substances of such level that when the fish are placed in an environment containing other toxic substances, the additional effects of the latter can tip the scales in favor of the appearance of toxic symptoms. This would be a case of the sum of effects of toxicants producing symptoms that are not observable in fish containing relatively low levels of total toxicants. Synergistic activity may be another argument to differentiate susceptible

fish from resistant fish, if the susceptible fish already contain toxicants.

On the other hand, the existence of resistant strains of fish may argue that prior exposures of these fish to toxic substances has activated the natural defense systems in the fish (e.g., via certain enzymes, as so-called mixed-function oxidases, in tissue cell components) that can intercept new toxicants that enter the body; such systems may not be active in the corresponding susceptible fish. This also may be an argument for the involvement of the phenomenon of antagonism, which may be operative in resistant fish. To illustrate how confusing the situation can be, research has shown that DDT and methyl parathion (insecticides) are more toxic to resistant fish than to susceptible ones. The conclusion was made that there are differences in the mode of action between the insecticides and the production of a greater overall stress from mixtures of the compounds (Ferguson and Bingham, 1966; Ferguson et al., 1966). At the present time, we do not fully understand the mechanisms involved in the actions of toxic compounds in fish. Much remains to be investigated relative to synergism, antagonism, resistant strains, and susceptible strains.

Finally, age of fish can be a factor in the toxicity of chemical substances. Work on four salmonid species has demonstrated that very young fish, e.g., 0.5-gram size, are more affected by certain insecticides than are fish slightly older, e.g., 1.6-gram size (Post and Schroeder, 1971). Age differences may be a factor, too, where pollutants appear to accumulate in some fish without major consequences because of differences in ability to eliminate pollutants by metabolism (Bache et al., 1972). An obvious correlation to age is size or weight, which indeed relates to the capacity for storage of pollution chemicals.

In conclusion, the interrelationships of chemical substances in aquatic living systems are extremely complex. Evaluations of the biological effects of toxic substances from pollution involve numerous considerations and assessments of interactions among natural marine life processes with the additional impact of the foreign compounds.

CONTAMINANTS DISCHARGED IN THE NORTHEAST PACIFIC

The principal sources of effluents discharged into the estuaries and marine waters of the Northwest are pulp and paper plants, municipal sewage, chemical and metal plants, food processing, rivers, and land runoff. The total amounts of effluents and the locations of outfalls have been documented for Oregon and Washington (Pacific Northwest River Basins Commission, 1973). The amounts of effluents were calculated on the basis of oxidizable organic material discharged but, because detailed composition of the effluents are unknown, interpretation about their impact on the aquatic environment must be limited primarily to effects on nutrients and dissolved oxygen.

Pockets of pollution occur in bays, inlets, and estuaries that have relatively high loads of waste. In some bays such as Coos Bay and Yaquina Bay, Oreg., oxygen levels fall to as low as 1-2 ppm in late summer when there is low inflow into the bays. Low dissolved oxygen and anoxic conditions in sediments have also been found during late summer in localized areas of Puget Sound and in Alaskan waters. Grays Harbor, Wash., has an intensified oxygen deficiency when deep water upwells and replaces the bay water during periods of low flow and high temperatures.

The lower Columbia River has had a special localized problem from periodic growths of slime. Wastes from pulp and paper production and from municipal sewage furnish nutrients that permit growth of *Sphaerotilus*, an organism between true bacteria and true fungi. The organisms combine with fiber, debris, and sand to form slime, which is aesthetically undesirable, coats fishing nets, annoys sport fishermen, and discourages water sports. There is no evidence that the slime is damaging to fish but its presence indicates that pollution problems exist. Occurrence of slime has decreased in recent years, concurrent with the discharge of less organic matter into the river.

The above conditions show that at times organic material has been added to some Northwest waters at rates faster than decomposition can occur. However, these obvious conditions do not furnish any clues about what materials are being added that may create more long lasting effects. A list of the principal known contaminants, their sources, physical characteristics, and reasons for concern from a biological standpoint are listed in Table 2.

Domestic Wastes

Both domestic and much of our industrial wastes are now processed in the same treatment plants. The composition of materials and the impact on the environment are different enough, however, that it is better to consider them separately. Communities and cities on the coasts of the Pacific Northwest and Alaska discharge both treated and untreated wastes into salt water. Reports on the present and projected waste loads have been published by the Pacific Northwest River Basins Commission (1973) and the Bonneville Power Administration (Bodhaine et al., 1965).

The principal problems from domestic waste water have been from bacteria, viruses, and organic material, but most of the bacteria and organic matter are now removed before discharge. Domestic wastes also contain significant chemical contaminants that enter treatment plants including petroleum oils, pesticides, herbicides, detergents, wastes from plastics, metals, and sometimes chlorine. Waste waters entering plants have been analyzed in more detail for both practical and technical reasons than the effluents, and few definitive statements can be made about either reactions or removal of the compounds during the treatment process. The effluents are monitored for characteristics such as coliform count, biological and/or chemical oxygen demand, total and volatile suspended solids, and phenols, in addition to total and ammonia nitrogen.

Widespread concern about what happens to sewage effluents in sea water is recent. Most work has been done with freshwater systems and the marine systems are less understood. The impact on marine systems and the materials that cause or do not cause problems must be defined before we spend time and money on treatment

Table 2.—Characteristics of contaminants discharged in coastal areas of the northeast Pacific.

Contaminants	Sources	Physical and Chemical characteristics	Biological aspects
Organic matter	Industrial effluents Sewage Land run-off Animals	Soluble, colloidal, particulate Causes turbidity Excessive amounts change character of bottom Excessive amounts cause anoxic conditions in water and sediments	Decomposition adds nutrients Decomposed by bacteria and fungi and thus undesirable growth often is increased Consumes oxygen Can concentrate other contaminants by adsorption Protects terrestrial bacteria and viruses in marine environment Can decrease light penetration and thus phytoplankton production
Synthetic organic compounds: Chlorinated hydrocarbons, herbicides, pesticides, polychlorinated biphenyls (PCB's), carbamates (Sevin), organic phosphates	Sewage and storm drains Industrial effluents Land Agricultural chemicals Atmosphere Sediments Ship repair, e.g., paint chipping Spraying: forests, fields, orchards, and urban gardens	Lipid soluble Slightly water soluble May be concentrated by oil slicks and by adsorption on particulates Transported in atmosphere Compounds can be synthesized to obtain specific chemical and physical characteristics. Thus, new compounds will continue to be developed. Decomposed by photolysis (light catalyzed)	Biological effects dependent on level of compounds, type of exposure, species, and environmental conditions including presence of other contaminants The greater the amount of chlorine in the molecule, the greater the toxicity, and the slower the degradation of the compound Stored in fat of animals Accumulate in food web Transported biologically by migratory species Compounds transformed by metabolism of animals Some species develop resistance Adversely affects reproduction and viability of young of many species Young more susceptible than adults Affects all trophic levels; often decreases food supply
Petroleum hydrocarbons	Oil spills Sewage and storm drains Industrial effluents Refinery waste Boats and ships Atmosphere Sediments	Varied, numerous compounds of many types Soluble, insoluble, volatile Altered by physical and chemical reactions, e.g., evaporation and photo-catalyzed oxidation Adsorbs on particles and settles in sediments Fresh oil, lighter than water, but partitions with volatiles evaporating, solubles dissolving, some floating	Decomposed by bacteria, action of animals not clarified Damaging to floating populations Effects of chemically altered compounds unknown Acute lethal toxicity by coating of gills and surfaces Sublethal problems unknown, polynuclear aromatics of greatest concern Paraffin hydrocarbons may have adverse effect on plants Food web accumulation unknown Can cause off-flavors in edible species Many species adapt to sublethal exposure Problems different for intertidal organisms, benthic organisms, finfish, and plankton
Metals	Natural levels Sewage Industrial effluents Mining (via rivers) Radionuclides Sediments Atmosphere	Solubility dependent on species, whether organic salt, organic complex, or organic compound Some airborne, e.g., lead Binds with organic matter in water and in sediments Reacts chemically with ions already in environments to change chemical form	Many metals are required nutrients Toxicity varies with chemical species; therefore, analyses and evaluation should be for amount in organic or inorganic form. Total amount gives little information Can accumulate in food web Transported biologically by migratory species Chemical species transformed by bacteria and animals Many biological species adapt to presence
Detergents	Domestic and industrial effluents	Soluble. Other characteristics depend on particular chemical compound Ionic and non-ionic forms Increase solubility of other contaminants, e.g., petroleum hydrocarbons	Toxicity varies with chemical compounds Synergistic effects with other contaminants, e.g., petroleum oil and detergent more toxic than either compound alone Causes frothing
Halogens Cyanids Ammonia	Sewage treatment Industrial effluents Animals Ammonia from nitrogen cycle (bacterial)	Chemical species determines solubility Chemical species related to pH Reacts with organic matter	Soluble forms often acutely toxic and lethal Problems worse in fresh water than salt water Diffusion and dilution important Irritants at sublethal levels
Sulfur compounds	Industrial effluents	Chemical species determines solubility Deposited in sediments	Compounds transformed by bacteria Hydrogen sulfide formed under anoxic conditions Hydrogen sulfide extremely lethal

(Continued on next page)

Table 2.—Continued.

Contaminants	Sources	Physical and chemical characteristics	Biological aspects
Heat: a) plume b) entrainment	Industrial cooling, including thermonuclear plants	Cooling system prior to return eliminates problem of temperature increase If not cooled, rapid diffusion important Effluent will contain other contaminants Increased temperature will increase solubility of other contaminants, and decrease oxygen levels	Permanent change in temperature will change flora and fauna Some species can adapt gradually and to a limited degree to temperature differences Heated effluents can be used for other purposes, e.g., aquaculture Synergistic effects with other contaminants Temperature changes can be critical in life processes of cold-blooded animals with effects on activity, oxygen consumption, feeding, reproduction, diseases
Change in flow of fresh water	Dams, flood control, stream diversions, fills, logging	Stratification of water column affects salinity	Salinity affects biota, estuarine conditions, marshes, river deltas Some species adapt to changes in salinity
Silt	Stream run-off Glacial debris Dredging Erosion	Turbidity Affects light and thus photosynthesis Transports other contaminants Settles and affects sediments Settles faster in salt water than in fresh water	If enough will clog gills and cause surface abrasions May change nutrients in water Other actions dependent on composition and other contaminants including amount of organic matter

systems that either may not do an adequate job or may do much more than is necessary.

Immediate toxicity is not a problem with effluents from domestic sewage. In fact, abundant marine life is usually found near discharge points where they feed on the nutrients furnished by the organic waste material. Potential problems are the longer term ones from accumulation of recalcitrant materials that degrade slowly, settling of organic materials that change the characteristics of organisms in the sediments, and introduction of toxic compounds, as well as introduction of bacteria or viruses that are pathogenic to humans or animals. The current state of our knowledge is such that we know so little about the processes that occur in marine waters that we cannot state with certainty which components may cause problems. Our knowledge, furthermore, is primarily about gross characteristics and the role of many trace components is still not clear.

Effluents

Effluent discharges from treatment plants are fresh water that contain variable kinds and amounts of materials. These can be roughly divided into soluble, floatable solids, colloids, and settleable materials. The dispersion and distribution of the soluble and colloid materials were discussed in the general section on contaminants.

The floatable, buoyant materials will rise to the surface where they become an aesthetic problem as well as cause turbidity in the upper layers and restrict light to phytoplankton with a possible effect on primary production. This problem is not serious in many estuarine areas because the amount of turbidity from this source is usually considerably less than the natural turbidity from rivers and land runoff. This is particularly true in the many areas where glacial streams are entering estuaries of the northeast Pacific Ocean. Oils and greases in the effluents will be in these floatables; thus the effluents may be a source of some of the oil slicks on the surfaces and beaches.

The denser effluents that settle near the vicinity of an outfall may influence the character of the sediments and the species of benthic organisms. This is again due to the organic material, and the rate at which these changes may occur is not clear. Pamatmat (1971) studied oxygen consumption of the seabed near a metropolitan discharge point about 3 years after the Municipality of Metropolitan Seattle started to discharge digested sewage sludge that contained oxidizable organic matter equivalent to about 0.3 percent biological demand. When oxygen consumption from sediments near the outfall were compared with consumption by sediments from other stations, no differences could be correlated with effects from settled sludge.

The total organic material added to the sediments also includes slowly degradable compounds. These include materials such as the chlorinated hydrocarbons and trace metals as well as other insoluble compounds that we do not now recognize as possibly detrimental to the marine environment.

The settling of organic materials to the sediments furnishes nutrients that permit abundant populations of benthic and epibenthic organisms. The condition of the demersal fish feeding in areas near outfalls is sometimes used to suggest whether problems are developing. Reports have been made on incidence of abnormalities and diseases of fish near sewage and industrial outfalls (Halstead, 1972; Southern California Coastal Water Research Project, 1973), but correlation with cause has two major difficulties. First, little is known about the incidence of abnormalities and disease in marine fish in uncontaminated areas. Second, many factors and interactions are occurring, and the cause and effect cannot be positively correlated in the state of our current knowledge. Nevertheless, studies and monitoring of the sediments and the animals living in and on these sediments offer the best clues available for detecting changes occurring in an area.

Bacteria and Viruses

Records from the past show that untreated sewage discharged into Northwest waters has resulted in polluted

beaches and infected shellfish. Most sewage is now treated and the waters are cleaner in the 1970's than they were in the 1950's. The problem has not completely disappeared, however, because evidence exists that current treatment methods do not kill all the viruses and possibly not all the bacteria present in the wastes. The survival of terrestrial bacteria in marine waters is particularly important when the survivors are human pathogens and food organisms are infected. Baross and Liston (1968) isolated *Vibrio haemolyticus*, a human pathogen, from Puget Sound waters, sediments, and shellfish and found the greatest numbers near sewage outfalls during the summer.

The survival time of bacteria and viruses in seawater has been the subject of a number of studies with conflicting results and differing interpretations. Bernard (1970) reviewed work with *Escherichia coli*, which is used as an indicator bacterium for sewage pollution. Temperature is important, with a longer survival time at colder winter temperatures, but *E. coli* does not reproduce at the colder temperatures. The organic material present is important in survival and distribution of both viruses and bacteria. Viruses bury into organic particles, survive, are carried with the particles, and probably use them as nutrients. The bacteria may be taken up by filter feeders or adsorbed on particles. When they settle to the bottom some remain viable for several weeks. Thus, sediments, which do not have the random fluctuations of water samples, may be used to obtain information about the sanitation of an area.

Most of the work on contamination of an area from sewage has been done with *E. coli*, but this gives only a gross evaluation of the situation. The classic use of *E. coli* as an indicator organism is now recognized as inadequate for suggesting possible hazards. Specific organisms must be isolated, their survival times determined, and definition made of their potential hazard to marine organisms and to man.

Chlorine is the agent usually used to eliminate or reduce microbial organisms in sewage effluents. Free chlorine is highly reactive and may alter the compounds present in the effluent. Thus, chlorides, rather than chlorines, are often found in the effluent and their discharge apparently does not cause a problem in marine waters because of the ions already present. Reactions with organic material in the effluent, on the other hand, may chlorinate some of the compounds, which may then become more insoluble, less degradable, and may have increased toxicity. This field needs much more investigation. As a result of potential problems, other procedures for sterilization are being investigated, including the substitution of ozone as the sterilizing agent.

Industrial Wastes

Industrial effluents vary not only from one industry to another and among different plants within the same industry, but also from day to day in any one plant. For this reason as well as because effluents from many industrial plants now enter sewage treatment plants, this discussion will be based on some important waste materials that are being released into Northwest waters. The difficulty with this approach is that a number of factors must be considered before potential hazards from contaminants can be evaluated. These include the fate of the contaminant during treatment and after it reaches the water, both synergistic and antagonistic reactions with other contaminants, and the quality and movement of the receiving waters.

Despite these problems, discussion of total effluent would be more difficult—not only because of variability but also because although materials used in a plant can be listed, detailed knowledge of the composition of effluents is not available and is difficult to determine. The major potential effects that are hard to recognize are those from trace components, including those formed during processing, that may accumulate to levels dangerous to the biota. Northwest industries and known toxic or lethal materials that may be discharged are listed in Table 3. Industries located on major rivers that flow into salt water are included because of the importance to anadromous fish and because many of the contaminants will reach salt water. Most of the industries using salt water for disposal of wastes, other than wood products and food processing, are on Puget Sound and the lower Columbia River. Puget Sound still has water of

Table 3.—Sources of contaminants in Northwest waters.

Source	Important Products	Comments
Major organic wastes: Pulp and paper Domestic sewage Food processing	Chlorine Petroleum oil, greases Acids Sulfur compounds NH_3, amines Metals Detergents Biocides Organic polymers Bacteria, viruses	Formation of anaerobic conditions and hydrogen sulfide. Buildup of slowly degradable materials. Widely distributed. Point sources, concentrations highest at discharge point. Domestic sewage also nonpoint source from septic tanks, land runoff.
Major inorganic wastes: Chloralkali plants Aluminum Alloy metals Petroleum refineries and drilling Nuclear plants	Metals and minerals Arsenic compounds Fluorides Chromates Cyanides Biocides Temperature Sulfur compounds Detergents Chlorine Greases, oils Phenols and phenolic compounds	Mercury not discharged by chloralkali plants. Industrial-Puget Sound, lower Columbia River. Mining-southeastern Alaska Point Sources, concentrations highest at discharge point.
Minor importance or nonpoint sources: Farm animals Grain elevators Shipyards Woolen mills Paints Sawmill, plywood, hardwood industry Logging practices Sand and gravel Recreation areas Septic tank discharge	Pesticides Herbicides Fungicides Total organic wastes Detergents Petroleum products Solvents Silt	Point sources, controlled or of small volume. Nonpoint sources, small amounts and general distribution.

high quality except in some of the inlets and bays. We do not know, however, how much waste can continue to be discharged without significant environmental deterioration.

Many chemicals are applied generally in industrial plants during processing and cleanup. These include lubricating oils used with processing machinery, detergents used for cleanup, biocides of various types, acids and alkali for pH control, as well as chelating agents for scale prevention and heat. Possible compounds in waste effluents include literally hundreds of compounds. Reviews (McKee and Wolf, 1963; Battelle's, Columbus Laboratories, 1971; Becker and Thatcher, 1973) have been made on the known effects of many of these compounds with data on the lethal quantities. Holland et al. (1960) reported the toxic effects of a number of organic and inorganic compounds to young trout and salmon. Their data on lethal effects of effluents and chemical compounds include the differences between fresh- and saltwater environments, indicating the type of behavior induced in the fish at sublethal levels. MacPhee and Ruelle (1969) used young chinook, *O. tshawytscha,* and coho salmon in fresh water to test the lethal effects of 1,888 chemicals.

Wood Products and the Timber Industry

The use of water by the timber industry and the use of water for aquatic animals has a long history of more conflict than any other uses of water in the Northwest. The present trend toward additional pollution controls, decreased use of water, and minimized volume of effluents by the wood products industry means that the current period is one of transition and may result in fewer problems in the future. Examination of past history is of value from the standpoint of residuals still in the sediments, recovery of areas, and to suggest possible effects from proposed dredging of sediments containing residual effluent material.

Logging Logging practices are of interest primarily for two reasons: 1) the possible effect on spawning streams of anadromous fish; and 2) the effects from storage of logs in the water.

The clear cutting of logs practiced in the Northwest and the construction of logging roads have a major effect on erosion of the hillsides and on water runoff, hence the rate of flow of streams. The erosion has caused siltation in the streams and resulted in changing gravel spawning beds to mud bottoms. Current logging practices can and often do use methods to minimize the effects on streams by leaving a buffer strip between the logged hillside and the stream and by not logging hillsides that have a high potential for erosion problems. Nevertheless, this is still an issue and each area proposed for logging must be studied to determine logging methods necessary to minimize effects on streams.

The use of water to store logs has been said to cause deterioration. Phenols, lignins, and other materials dissolve whereas pieces of bark and wood chips collect in the sediments. The degree to which these cause problems has not been clarified.

Forest Products The forest products industry has been a major user of water in the Northwest both during processing and for disposal of waste. The industry manufactures pulp and paper, hardwood and softwood veneers, hardwood and softwood plywood, hardboard, and treated wood products such as railroad ties, poles and piling, and fence posts, as well as timber and lumber that are fire resistant, insecticidal, or fungicidal. Plants are located on both fresh and salt water and their effects on the biota have been studied for 40 years. The amount and composition of effluent from the plants vary not only in the different segments of the industry but also from plant to plant within each segment. Technology exists to eliminate or minimize the amounts of effluents and to detoxify all effluents before discharge. Plants manufacturing veneers, plywood, hardboard, and treated products minimize water use and are not discharging residual treated effluents directly into water.

Construction of new plants is expected to include methods to eliminate effluents. Although older plants may be granted interim variances for their disposal methods, they are expected to minimize effluents discharged into waters. The discharge of organic material is nearly eliminated by reuse of waste water or by chemical and/or biological oxidation. The principal problem with achieving the ideal zero elimination of discharged waste is that the amount of water used often precludes not returning some effluent. The pulp and paper industry has the biggest problem in controlling effluents. The industry has taken many steps in the last 20 years to decrease pollution effects. These have ranged from changes in processing to utilization of waste to detoxification of wastes. Recently a major processor announced plans to prepare pulp by a mechanical process. This method will result in a major reduction in the volume of water used and consequently will decrease the need to dispose of waste products in water. Other possible effects are unknown.

The pulp and paper industry has been a major source of pollutants that have affected marine biota of the Northwest. Most of the research on pollution from forest products has been on discharges from the sulfite and kraft mills. The literature contains conflicting results but enough work has been done that it is possible to draw some conclusions. A number of explanations can be made for conflicting information and some are worth mentioning because they apply to evaluation of other types of pollution. Two obvious reasons for discrepancies in results are that both effluents from different plants and conditions in the receiving waters vary for different plants. Another important reason is that all too often symptoms of a problem were observed and expensive treatments instituted, but major problems still existed, nevertheless, because the basic causes were not known and treatment of symptoms has not alleviated the problem. Parker and Sibert (1972) have shown, for example, that a major problem still existed from low levels of dissolved oxygen after reduction in the amount of organic matter from effluents of a pulp mill plant that were added to the upper fresh water layer of a stratified inlet (Alberni Inlet, British Columbia). The suggested cause was that the dark stain from the effluent blocked photosynthesis, affected the oxygen content even below the halocline, and played a major role in reducing the productivity at the freshwater-saltwater interface.

Sibert and Parker (1972) then developed a numerical model that was based on results from both laboratory chemostat studies and field observations. They concluded that effects from removal of organic matter did not penetrate the lower saltwater layer and thus had little effect on oxygen content below the halocline and that primary productivity in the upper layer was below normal until 90 percent of the stain was removed. This work did not include information about the effects on various trophic levels from removal of nutrients furnished by organic materials in the effluents.

The excellent work above was based on one aspect of the effects of pulp mill effluents—that on dissolved oxygen. A number of other aspects must be included in considerations about biological effects from the effluents. The untreated waste has a direct lethal toxicity for fish, but much of the components causing acute effects is removed along with the organic material during bacteriological treatment and oxidation of the effluent. The chlorine used to bleach pulp waste reacts with the organic material present and most of the chlorine is removed from the effluent before discharge. However, a potential problem exists in that some organic compounds in the effluent may be chlorinated and their toxicity increased. Servizi et al. (1968) investigated this with two compounds which could be formed from lignin during the pulping and bleaching process and found that chlorination did not increase their toxicity to fish but that the chlorinated compounds were degraded during treatment with activated sludge. Problems could result if there are chlorinated compounds that are not degraded because they may then accumulate in the food web if their ultimate disposal is in the marine environment.

The total composition of kraft or sulfite wastes has never been determined and both acute and subacute studies have usually been made on the effluents. A number of these studies, as well as avoidance studies, have been made on salmon, oysters, and organisms of the lower trophic levels that furnish food for fish. Since the effluents are now being treated before being discharged, this extensive literature will not be reviewed. Readers wishing to pursue this can start with the following references: McKernan et al., 1949; Williams et al., 1953; Alderdice and Brett, 1957; Gunter and McKee, 1960; Servizi et al., 1966; Parrish and Horton, 1971.

Untreated kraft mill waste has a number of toxic components. Neutralization of waste eliminates up to 75 percent of the toxicity. Volatile sulfides and mercaptans also contribute to lethal effects but these can be removed prior to discharge. The nonvolatile components also have significant toxicity, however. Leach and Thakore (1973) fractionated effluents from a kraft mill effluent resulting from pulping of 50 percent Douglas fir and 50 percent western hemlock and assayed the lethal levels on juvenile coho salmon. Resin acid soaps accounted for 82 percent of the toxicity of the nonvolatile constituents. The remaining toxicity was due to sodium salts of unsaturated fatty acids. A 10 percent reduction in fatty acid concentration eliminated their lethal effects. The variations in lethal levels for different kraft mill effluents probably is related to changes in the type and quantity of nonvolatile components, since these will vary depending on the raw material and processing methods.

Despite current trends toward decreased discharge of organic material from pulp and paper plants, large amounts have already been dumped in the waters and the question of what is happening in these areas is important. Servizi et al. (1969) made some interesting comparisons of toxicity to sockeye, *O. nerka*, and pink, *O. gorbuscha*, salmon from sediments from two areas. Sediments in one area were deposits primarily from sulfite pulp, board, and paper mills with a smaller contribution from sewage waste treatment. Sediments from a nearby area were deposits primarily from the silt load of a river. The polluted sediment had no benthic organisms such as crabs and worms. It had an oxygen demand of 6 ppm and contained gases such as hydrogen sulfide (H_2S), methane, and carbon dioxide. Samples of this sediment caused 100 percent mortality to sockeye smolts at concentrations of 1 percent sediment material. This level contained 2.3 ppm H_2S. At a level of 0.3 ppm H_2S no mortality occurred, but the fish were in distress as detected by coughing and frenzied swimming. Hydrogen sulfide was shown to be the primary problem but pulp fibers were noted to clog gills. The sediments of natural silt on the other hand contained small crabs and worms. It had a significant oxygen demand, two-thirds as much as that of the polluted sediment, but caused no mortality to fish within 24 hours at concentrations of 5 percent sediments.

The buildup of pulp waste was not as great in the above polluted sediment as it is in some sediments because the area had been dredged within the previous decade. The above study pinpoints the problems that pulp waste decays relatively slowly and that any decision to remove this type of waste material from sediments must be made cautiously.

Agriculture and Food Processing

Contaminants from agriculture and food processing may be both at a specific place, such as processing plants and grain elevators, or may be rather generally distributed, such as animal waste and land runoff of chemicals used in farming. The wastes from processing plants near urban areas are generally discharged into sewage systems and thus organic material is removed. Plants in more isolated areas are now being required to install methods to remove the organic material. Organic wastes from farm animals are more difficult to handle and problems have developed where there are concentrations of animals, such as in dairy herds and poultry farms. The agriculture industry uses large quantities of fertilizers, pesticides, herbicides, and fungicides. When these chemicals are properly applied large amounts will not get into the water, but even under favorable conditions some do wash into the waters via land runoff. Research is currently being conducted on the fate of many of these materials in soils to establish the conditions that determine what and how much of the compounds or their degradation products will enter the waterways. This information is essential to define potential problems in the aquatic environment from use of these materials.

The Chemical Industry

The chemical industry does not discharge large amounts of decomposable, oxygen demanding, organic wastes; components of the effluents, however, may be the types that are lethal and accumulate in the environment.

Aluminum Production The aluminum industry developed in Oregon and Washington following World War II because of cheap, abundant electric power and in turn became a reason to expand the power supply from the Columbia River. The industry also utilizes large amounts of water and has significant volumes of heated effluents. Ponds are often used to cool effluents and to remove the solids that settle. Cyanides and fluorides are present in effluents entering water. Welch et al. (1969) examined marine organisms near a diffuser from an aluminum plant on Puget Sound and reported that the number of species of invertebrate benthic fauna was lowest in the vicinity of the diffuser and increased with increasing distance north and south of the diffuser. This study was made too soon after the opening of the plant to make any comments concerning possible effects from accumulation of wastes.

Metals No iron ore is reduced to pig iron in this area but scrap is melted so that there are steel mills, ingot forgers, and foundries. Metals produced include ferrosilicon, ferromanganese, silicomanganese, and silicon. Components of effluents include acids, cyanide, and arsenic and chromic compounds, as well as oil and grease.

Chloralkali Plants Effluents from these plants were formerly a source of mercury in the aquatic environment, but the discharge of mercury and mercury compounds has been stopped. Levels of other discharged compounds are restricted and include chlorine (5.0 ppm maximum in effluent), alkali, phenols, and phenolic compounds.

Petroleum Refining and Drilling Petroleum refineries are of comparatively recent construction and consequently the quality and quantity of waste products are controlled. Effluents vary from plant to plant and from day to day in a single plant but components may be acids, alkalies, sulfides, phenols, ammonia, carbon disulfide, heat, and many others, in addition to oil and petroleum products. Refinery effluents, like most industrial effluents, can be treated so that they are not toxic to aquatic organisms. Underwater drilling is not permitted in Puget Sound, but it is occurring in Alaskan waters, including Cook Inlet. Environmental effects on marine organisms from this drilling are currently being studied. Environmental aspects of transportation of petroleum are discussed by Clark (1976).

Nuclear Plants Three possible sources of radionuclide contamination have occurred in the Northwest: atomic works, thermonuclear power plants, and experimental atomic blasts such as were tested at Amchitka Island in the Aleutian Islands. All of these sources have been monitored. The physical and biological distribution of radionuclides in the Columbia River, the estuary, and the adjacent ocean waters has been extensively covered by Pruter and Alverson (1972). The first reactor at Hanford went into operation in September 1944, and the amounts discharged have varied at different periods since then. Most of the materials discharged into the river are deposited in river sediments. The primary radionuclides discharged into the ocean are ^{65}Zn and ^{51}Cr. A number of pelagic and benthic fish and shellfish concentrate ^{65}Zn, but levels were not high enough to be of concern from the standpoint either of human health or of pathological conditions in the biota.

All contamination from thermonuclear power plants is not connected with radioactivity but also with production of heat and with chemicals used in the plant. Becker and Thatcher (1973) compiled a review of toxicity of nonradioactive chemicals actually or potentially associated with the operation and maintenance of nuclear power plants and cooling towers.

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MFR PAPER 1219

Clark

Impact of the Transportation of Petroleum on the Waters of the Northeastern Pacific Ocean

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INTRODUCTION

Petroleum and other hazardous chemical products are shipped in large amounts over the waters of the northeastern Pacific Ocean and along its coastal waterways. The variety and quantity of these toxic materials moving across the oceans are steadily increasing in response to expanding industrial needs. Spills and other accidental discharges of such materials can seriously impair water quality at sites near or remote from the sources of discharge. Since petroleum makes up nearly 95 percent of the bulk of hazardous cargo moved in the northeastern Pacific, this discussion will concern itself with the magnitude and impact of petroleum and its products on the water quality and the living marine resources.

For the last 100 years, petroleum on the west coast has been transported over the waters of the northeastern Pacific—first in small wooden barrels and now in large tankers of 130,000 deadweight tons (dwt) or larger. Until the last decade or so, most of the oil shipped along the western margin of the North American continent was contained in small tankers and barges (18,000 dwt or less), carrying refined petroleum products from southern California refineries to nearby coastal markets.

In the last two decades, the markets for petroleum products have increased in size while the production of crude oil in the southwestern United States has decreased. Consequently, it has become expedient to build new refineries nearer the developing markets, and it has become necessary to transport crude oil greater distances from domestic and foreign oil fields by pipelines and supertankers. This increase in magnitude of the transportation of petroleum and its refined products has magnified the potential risk of oil pollution in the marine environment.

TRANSPORTATION AND PRODUCTION

Historically, petroleum products were refined near the oil fields in California and then shipped up the west coast in small coastal tankers. In the mid-1950's new refineries were built in Washington and British Columbia to produce petroleum products for local consumption from crude oil delivered by pipeline from Alberta, Canada. Oil was discovered in the late 1950's in the Kenai Peninsula near Anchorage, Alaska; two small refineries were built there for Alaskan needs, and the excess crude oil was shipped to California for refining. By the early 1970's the overall production of crude oil on the west coast was declining while the demand for products in the same geographic area was increasing at approximately 4.5 percent annually (Oil and Gas Journal, 1971). Although the petroleum industry has predicted that higher energy costs, conservation efforts, and slower economic growth will reduce the average growth of petroleum use to about 2.2 percent annually over the next decade (Exxon USA, 1976), the projected west coast demand for 1976 is 4.9 percent greater than the use in 1975 (Oil and Gas Journal, 1976). The deficiency in crude oil production (53.3 percent) compared to consumption of refined products has, in the area west of the Rocky Mountains, required the importation of large volumes of foreign (South American, Indonesian, and Middle East) crude oil carried in increasingly larger tankers—in the 100,000-130,000 dwt class—although very large crude carriers (VLCC) of 226,000-400,000 dwt are already in use on other worldwide routes.

The utilization of the large oil reserves (20-40 billion barrels; 1 U.S. barrel is 42 gallons) discovered in the Alaskan Arctic in the late 1960's can decrease the need to import crude oil to the west coast. A 48-inch diameter Trans-Alaska Pipeline System (TAPS) is being completed from Prudhoe Bay to the ice-free port of Valdez, where crude oil will be loaded eventually at 2 million barrels/day into large tankers and supertankers for delivery to refineries in the Puget Sound area of Washington and the San Francisco and Los Angeles-Long Beach areas in California, with possible shipments to the east coast through the Panama Canal (Fig. 1). This system, assuming a completion data of 1977, envisions the use of more than 35 modern tankers ranging in size from 45,000 dwt to 250,000 dwt, many of them yet to be built. All will be U.S. built and manned (Table 1).

PRUDHOE BAY CRUDE OIL

The Prudhoe Bay oil field (Sadlerochit oil pool) is North America's largest known petroleum reservoir; the American Petroleum Institute places the recoverable reserves at a conservative 9.6 billion barrels of oil, and the American Gas Association estimates 26 trillion cubic feet of gas. The initial production is planned at 1.2

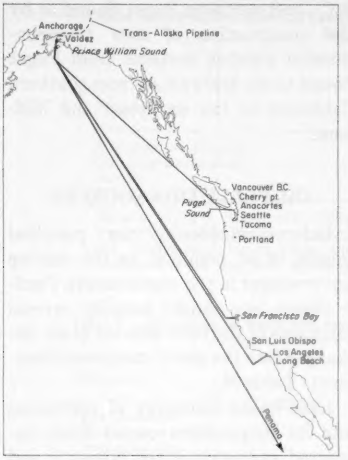

Figure 1.—Crude oil transportation routes from the southern terminal of the Trans-Alaska Pipeline System at Valdez to west coast ports.

million barrels/day for pipeline delivery to Valdez. This single 46-square mile field is expected to produce for 10-11 years without secondary recovery (water or gas drive to force the oil from the reservoir rock structure to the well)[1]. There are other geological basins, including Naval Petroleum Reservation Number 4 adjacent to Prudhoe Bay, having sedimentary structures which point to further oil reserves in Alaska; therefore, tanker transport of crude oil from Alaska can be expected to increase beyond the levels predicted for TAPS.

Chemical analysis reveals Prudhoe Bay crude oil to be an average crude oil. Comparisons of chemical analyses of Prudhoe Bay crude oil (Sag River) with typical South Louisiana and one of the Kuwait crude oils is made in Table 2.

SUPERPORTS AND SUPERTANKERS

To meet the energy needs of the western United States and Canada, it is predicted that there will be increasing reliance on sources such as Alaskan and foreign regions, requiring waterborne delivery of petroleum. The increase in tanker traffic can take place by either increasing the number of medium (less than 40,000 dwt), large (around 70,000 dwt), or supertankers (120,000-180,000 dwt) or by turning to very large crude carriers (VLCC—above 200,000 dwt). In general, the cost per unit ton of crude oil decreases with increases in vessel size and route distance up to certain optimum combinations.

As the size of the tankers increases, the requirements for adequate port facilities also increase to the point that existing facilities on the west coast will be inadequate for the size of some of the tankers now under construction or on order. Superports are usually designed to accommodate vessels with drafts up to 100 feet (500,000 dwt vessels or less). The type and geographic location of such facilities derive from three considerations: 1) the depth of the water, 2) the congestion of ship traffic, and 3) the nature of the commodity to be transported through the facility (dry bulk commodities like grain, coal, or ores compared with liquids such as crude oils, refined petroleum products, petrochemicals or liquified gases). The facility must

[1]State oil and gas division testimony before Legislative Interim Pipeline Impact Committee. *In* The Alaska Series: Special Reports for Management, Ser. Rep. 8, Issue 3 (August) 1971, [Anchorage, Alaska], 4 p. (Processed.)

Table 1.—Typical tankers to be used on the Valdez-west coast run at 2 million barrels per day [1].

	Vessel size				
No. of vessels	Tonnage (dwt)	Length (ft)	Draft (ft)	No. of cargo tanks	Crash stopping distance (ft)
1	45,000	—	—	—	—
3	60,000	731	43.2	13	4,300
2	70,000	810	43.5	18	9,000
3	75,000	810	41.5	15	5,225
2	80,000	811	43.2	13	5,000
2	86,000 (&90,000)	892	47.5	14	—
16	120,000	883	51.8	15	10,000
5	130,000	—	—	—	—
1	150,000	—	—	—	—
2	180,000	952	59	—	—
8	250,000	1,143	65.5	15	13,500
0	380,000	1,190	101	20	—

[1]Sources: Alyeska Pipeline Service Co., 1971, Description of marine transportation system—Valdez to West Coast ports. Submitted to U.S. Dep. Interior, 21 July, 65 p.; Final Environmental Impact Statement, 1973, Maritime Administration Tanker Construction Program, Dep. Commerce (NTIS Rep. No. EIS 730725-F); Alyeska Pipeline Service Co., 1973, The marine transportation of Alaska North Slope oil, Anchorage, 24 p.

Table 2.—Analysis of Prudhoe Bay, South Louisiana, and Kuwait crude oils [1].

	Prudhoe Bay	Coastal Louisiana	Kuwait
Gravity, specific, 15°C	0.848-0.893	0.84	0.889
Gravity, °API	27.0-27.8	32-37	31.3-31.4
Pour point, °C	—10	—	—32
Sulfur, wt %	0.82-0.94	0.2-0.3	2.50
Nitrogen, wt %	0.23	0.7	0.14
Viscosity, 38°C, cSt	14.0	—	9.6
Hydrocarbons			
Paraffins, wt %	27.3	28	34
Aromatics, wt %	25.3	19	24
Naphthenes, wt %	36.8	44	20
Others & loss, wt %	10.6	9	22
Nickel, ppm	8-10	2-3	8-9
Vanadium, ppm	16-18	1-2	27-28
Residue, high-boiling, °C	343	315	371
Yield, wt % [2]	52.6	55	50.7
Gravity, specific, 15°C	0.961	(0.90)	0.974
Sulfur, wt % [3]	0.79	0.23	4.15
Nitrogen, wt % [3]	0.189	0.04	—
Nickel, ppm	17	[3]20	18
Vanadium, ppm	35	[3]5	53
Viscosity, kinematic, 100°C	36.5	[3]700	64.4
Pour point, °C	18	—	21
Asphaltenes, wt %	1.7	[3]0.85	2.7

[1]Brunnock, Duckworth, and Stephens (1968); Roselius and Steffens (1971); Coleman et al. (1973); Vaughan (1973); Alyeska Pipeline Service Co. (text footnote 3); Pancirov, R. J. 1974. Compositional data on API reference oils used in biological studies: A #2 fuel oil, A Bunker C, Kuwait crude oil, and South Louisiana crude oil. Esso Res. and Eng. Co., Linden, N. J., Rep. AID. IBA. 74, 6 p., 4 app. p.
[2]Based on percent in total crude.
[3]Above 540°C (1,000°F).

either be located offshore far enough to obtain the required water depths, or there must be considerable dredging at an inshore (shallower) site; the farther offshore the port facilities are placed, the less the congestion of existing coastal ports and the lower the chances of collision[2].

Deepwater petroleum superports fall into two principal categories: moorings and fixed structures. The conventional anchored buoy mooring maintains a fixed tanker position and orientation by mooring lines to a number of buoys or by a single point anchored buoy system around which the tanker is free to rotate. Fixed structures consist of a single pile mooring pier or they may take the form of artificial or sea islands. Most existing facilities (except for a conventional buoy mooring at San Luis Obispo off California) consist of a pile mooring pier connected to landside storage with a road and pipeway built on pilings.

There are a number of different offshore facilities which may be developed to fill the need for handling supertankers and VLCC's. Such facilities range from a single point mooring buoy, with an underwater pipeline to shore, to a large island with protected berths and storage for oil. Each will have its own environmental impact, determined not only by its design, but also by its location.

There are several potential crude oil superport sites on the west coast having existing facilities, such as oil company-owned refinery docks or moorings at Cook Inlet, Alaska (35,000 dwt, current maximum vessel size); Vancouver, B.C. (44 feet—usual safe operating draft; 125,000 dwt); Cherry Point (42 and 65 feet; 80,000-150,000 dwt), Anacortes (46 and 48 feet; 60,000-80,000 dwt), and Tacoma, Wash. (35 feet; 50,000 dwt); Portland, Oreg. (38 feet; 35,000 dwt); and San Francisco (35 feet; 55,000 dwt), Port San Luis Obispo (32 feet), Long Beach (54 feet; 120,000 dwt), and Los Angeles Harbor, Calif. (51 feet; 110,000 dwt) (International Petroleum Encyclopedia, 1971, 1975; Pacific Northwest Sea, 1974).

Various proposals have been suggested for upgrading these facilities to receive the supertankers and VLCC's. A common solution entails extending the terminal pier facilities into deeper water, although in some cases entirely new reception facilities have been proposed, such as a single deepwater oil transfer facility for the Pacific Northwest just inside the entrance of the Strait of Juan de Fuca, off central California, or in the Los Angeles-Long Beach area. Offshore transfer facilities along the exposed coasts of northern California, Oregon, Washington, or British Columbia do not appear to be economically or environmentally attractive.

Due to the increasing petroleum needs of the United States and Canada, it is becoming apparent that the crude oil requirements of the west coast refineries already located near or on tidewater will have to be supplied from the diminishing indigenous pipeline-delivered oil (California and northwestern British Columbia) supplemented by an increasing inflow of tanker-delivered crude oil from Alaska, South America, and the Middle and Far East. It is conceivable that in the next decade most of the existing and planned refineries in British Columbia, Washington, Oregon, and northern California will be receiving all of their crude oil feedstocks by tanker. The west coast could even serve as a transshipment point for forwarding oil to Midwest refineries, either through existing and expanded pipeline systems such as by reversing the present westward flow of Alberta crude oil over the Trans-Mountain Pipeline to Vancouver, B.C., and northern Puget Sound or by the construction of new transcontinental pipeline systems from Puget Sound to the Midwest or from southern California to the southeast and Midwest.

OIL POLLUTION SOURCES

Before considering the potential impact of oil pollution on the marine environment in the northeastern Pacific Ocean, one should consider several estimates of the total amount of oil discharged into the global marine environment (Table 3).

Land-based discharge of petroleum and its by-products comes from untreated and semitreated domestic and industrial wastes, spent marine lubricants, and incompletely burned fuels including those from atmospheric fallout. For instance, the input of oil into marine waters off southern California has been estimated (Table 4).

It is estimated that nearly 2 million tons of used lubricating oil is unaccounted for each year in the United States alone, a significant portion of which reaches our coastal waters. The quantities of oils generated and methods of waste oil disposal for the state of Washington (1971) are given in the following table for comparison. Approximately two-thirds is disposed of directly into the environment or is unaccounted for (Table 5).

In regard to marine operation losses, on the Pacific coast the existing domestic tankers do not use the load-on-top method for cleaning ballast water from the cargo tanks because the west coast runs are too short to

[2] Maritime Administration. 1973. Final environmental impact statement: Maritime Administration Tanker Construction Program. U.S. Dep. Commer., Washington, D.C., NTIS Rep. No. EIS 730725-F, p. IV159-IV169.

Table 3.—Estimates of annual petroleum discharges into the global marine environment compared with a global petroleum production (1971) of 2,978,400,000 tons.

Type of discharge	Estimated tons of oil contributed annually[1]		
	Wardley Smith	Blumer	Natl. Acad. Sci.
Land-based discharges:			
Refineries, petrochemical	300,000		200,000
Waste oil, runoff, sewage, atmospheric fallout	500,000	2,000,000	3,100,000
Marine operation losses:			
Tankers, using load-on-top	100,000	3,000,000	310,000
Tankers, not using load-on-top	600,000	1,500,000	770,000
Bilge discharges	50,000	500,000	500,000
Accidental discharges	200,000	—	553,000
Offshore production		—	80,000
Oil seeps		—	600,000
Totals	1,900,000	7,000,000	6,113,000

[1]Wardley Smith (1973); Blumer (1971); National Academy of Sciences (1975).

Table 4.—Estimates of annual petroleum input in waste waters off southern California [1].

Type of water	Mass emission rate in tons per year	
	Total oil and grease	Petroleum only
Municipal waste water	65,000	32,000
Industrial waste water	2,200	2,200
Runoff	4,400	?

[1]Source: Philip N. Storrs. 1973. Petroleum inputs to the marine environment from land sources. Background papers for Ocean Affairs Board, Natl. Acad. Sci., Workshop on Inputs, Fates, and Effects of Petroleum in the Marine Environment, 21-25 May 1973, Airlie, Va., Vol. 1, p. 50-58.

Table 5.—Quantities of waste oils generated and methods of waste oil disposal employed in Washington State during 1971[1].

Waste oils	Quantity (gallons)
Type generated	
Automotive lubricating oils	10,599,183
Industrial oils	5,871,879
Tank cleanings	2,137,570
Total	18,608,632
Method of disposal	
Returned to California refineries (Ultimate fate unknown)	828,424
Rerefined	2,570,972
Used as road oil	7,609,866
Dumped on ground surface	2,843,419
Disposed of at a sanitary landfill or garbage dump	772,773
Reused as a lubricant or form oil	140,415
Used as fuel	2,735,950
Dumped into sewer or storm drain	27,416
Unaccounted for	1,079,397
Total	18,608,632

[1]Source: A report on oil pollution prevention and control. Washington State Dep. Ecol., Olympia, Wash., 1973, p. 1-6. (Processed.)

allow for proper separation of the oily residues from the ballast water. There are few crude oil loading ports maintaining shore facilities for removing oil from ballast water for these tankers; these tankers now have to discharge some of their oily ballast water directly into the northeastern Pacific Ocean. At Valdez, however, Alyeska Pipeline Service Company will provide ballast water treatment for incoming tankers which will lower contamination down to 10 parts per million oil in the final effluent discharge. Bilge water containing oil can be pumped from any vessel—not only oil tankers. Governmental regulations prohibit pumping bilges within coastal zones from 50 to 100 miles of shore.

Another category of petroleum loss into the marine environment is from accidental discharges: collisions, groundings, structural failures, rammings, fires, explosions, breakdowns, and human error. Although oil discharged accidentally comprises only 10 percent of the global losses, they are more noticeable because most of these accidental discharges occur in port or very near the shore. One study of major marine oil spills indicated that 75 percent were from vessels, 90 percent of which were tankers, and half of the spills were due to tanker groundings. Eighty-five percent of the spills occurred within 50 miles of a port (Gilmore et al., 1970).

Offshore oil production on the west coast is currently concentrated in the Santa Barbara-Long Beach area of southern California and in the Cook Inlet area of south-central Alaska. The Santa Barbara blowout of 1969 is an example of a large-volume, man-caused discharge of oil from offshore production. The total input (including shore-based petroleum recovery resources) has been estimated to be of the order of 0.3 percent of the total oil produced or handled in Cook Inlet (Kinney, Button, and Schell, 1969).

The contribution made by natural oil seeps to the contamination of the northeastern Pacific waters is difficult to estimate, yet the coastal margins of this region contain geological areas capable of measurable oil seepage. Seeps have been reported in the following nearshore areas:

Norton Bay	Bering Sea
Androncia Isl.	Shumagin Islands
Puale Bay to Wide Bay	Alaska Peninsula
Kamishak Bay	Alaska Peninsula
Chinita Point	Alaska Peninsula
Don Miller Hills	South-cent. Alaska
Nichawak Hills	South-cent. Alaska
Robinson Mts.	South-cent. Alaska
Samovar Hills	South-cent. Alaska
Lacey-Hoh River	Washington coast
Coal Oil Point	California coast
La Goleta	California coast
Santa Monica Bay	California coast

While there is moderate to high potential for seepage in these regions, the input is still low compared with man-caused oil pollution (Table 6).

IMPACT OF INCREASED CRUDE OIL TANKER TRAFFIC ON THE NORTHEASTERN PACIFIC

The impact of the increase in marine transportation of petroleum in the northeastern Pacific Ocean following the discovery of oil in Alaska is expected to be considerable, due to an increase in vessel size and traffic, and, consequently, a potential increase in intentional and accidental discharges.

Table 6.—Areas of geological potential seepage in the continental margins of the northeast Pacific Ocean.[1]

Area	Seepage potential	Gross area (1,000 mi²)	Seepage prone area (1,000 mi²)
Bering shelf	Low	656	524.6
Aleutian Chain/Cook Inlet	Moderate	18	12.6
Gulf of Alaska	High	77	53.9
Northeast Pacific margin	Moderate	151	60.4
Southern Calif./Baja basins	High	361	144.4
Central America Pacific margin	Moderate	318	127.2

[1]Source: Richard D. Wilson. 1973. Estimate of annual input of petroleum to the marine environment from offshore production operations. Background papers for Ocean Affairs Board, Natl. Acad. Sci., Workshop on Inputs, Fates, and Effects of Petroleum in the Marine Environment, 21-25 May 1973, Airlie, Va., Vol. 1, p. 59-96.

The prediction of the amount of oil lost and the frequency of accidental oil spills from different causes at different places is an important part of the evaluation of the environmental impact of the marine tankers fed by TAPS. Various estimates of the volume of oil discharges in the northeastern Pacific Ocean are listed in Table 7.

Available information indicates that accidents and intentional discharges of oil will continue to occur in spite of technological advances and the existence of the most stringent regulations. Thus a gradual increase in pollutant hydrocarbons can be expected from the increased tanker traffic in the northeastern Pacific, especially in the nearshore areas (Gilmore et al. 1970)[3].

The northeastern Pacific is relatively unpolluted compared with much of the world's ocean areas (Butler, Morris, and Sass, 1973). The background hydrocarbon level is relatively low in Port Valdez, Prince William Sound, and Puget Sound, and even though it is not clear what the acute and long-term effects of oil upon the marine environment would be, it is expected that where biological effects appear they would be most apparent in areas such as the above, which have restricted circulation[4].

The intentional discharge of ballast water into the Gulf of Alaska beyond the 50-mile limit—as permitted by state, federal, and international regulations, in addition to the accidental loss of oil—poses a threat to the marine ecosystem, if allowed to increase without control; the adverse effects cannot yet be precisely evaluated or predicted because too many variables are involved. It is hoped that the application of modern technology and enlightened regulations will minimize such discharges.

CHEMICAL AND PHYSICAL FATE OF OIL

Crude petroleum is a complex mixture of natural products and includes many thousands of different compounds. Petroleum and its hydrocarbons have been found to be remarkably stable in the marine environment.

Oil spilled at sea undergoes rapid changes which include spreading to form slicks, evaporation of the more volatile components, dissolution of the more soluble components, emulsification, and oxidation by photochemical and microbial processes (Fig. 2). Important in this phase of petroleum dispersion, as well as in the process of emulsification, are the surface-active components of the petroleum—in particular, the nitrogen-, sulfur-, oxygen-containing heterocyclic compounds. Evaporation selectively depletes the most volatile components, but leads to little or no fractionation of different hydrocarbon types having approximately the same boiling points. The dissolving of hydrocarbons into seawater follows the same pattern as evaporation, with the difference that selective dissolution of polar aromatic and oxygenated compounds tends to make them relatively more soluble than nonpolar components with the same boiling point. Oil can adsorb onto particles or be compacted in the fecal matter of small marine organisms; in either case, once the particle becomes heavier than water it sinks and the oil can become incorporated into the sediments (National Academy of Sciences, 1975).

The residue or relatively insoluble and nonvolatile material from petroleum spilled on the sea surface is one source of raw material for pelagic tar balls. Slicks on the sea surface are a transient phenomenon lasting only weeks at most. Pelagic tar balls are also relatively transient, lasting at most for a few years. The ultimate fate

[3]Alyeska Pipeline Service Company. 1971. Supplement to description of marine transportation system—Valdez to West Coast ports. Letter submitted to U.S. Dep. Int., 24 Sept. 1971, 4 p., 6 attachments.

[4]U.S. Department of the Interior. 1972. Final Environmental Impact Statement Proposed Trans-Alaska Pipeline, Washington, D.C., Vol. 4, p. 460-487.

Table 7.—Summary of volume of potential spills associated with the proposed northeast Pacific Ocean marine transportation system at a 2-million-barrel/day pipeline throughput (all volumes in tons/year)[1].

Type and total discharge	Contiguous zone: Valdez	Puget Sound	San Francisco	Los Angeles	Total	Open ocean	Total
Intentional discharge							
1. Ballast treatment facility[2]	650-1,300	—	—	—	650-1,300	—	650-1,300
2. Compliance with 1969 amendments,[3] or	—	—	—	—	—	6,650	6,650
3. 100% load-on-top, or	—	—	—	—	—	27,000	27,000
4. Uncontrolled tank cleaning	—	—	—	—	—	74,000	74,000
Unintentional discharge							
5. Transfer operations-PIRS[4], or	150.0	15.0	40.0	57.5	262.5	—	262.5
6. Transfer operations-Milford Haven[5]	70.0	6.5	19.0	27.0	122.5	—	122.5
7. Casualty losses-restricted waters-PIRS, +	90.0	10.0	25.0	35.0	160.0	—	160.0
8. Casualty losses-open waters-PIRS	2.0	—	—	—	2.0	—	2.0
9. Total (7 & 8), or	92.0	10.0	25.0	35.0	162.0	—	162.0
10. Casualty losses-worldwide analysis[6]	—	—	—	—	—	—	19,200
Total discharge							
Case I : lines 1 + 6 + 9							[7]≈ 950
Case II : lines 1 + 6 + 10							20,100
Case III: lines 2 + 5 + 10							26,100
Case IV: lines 3 + 5 + 10							46,450

[1]U.S. Department of the Interior (see text footnote 4).
[2]Alyeska Pipeline Service Company. 1971. Various submissions to the U.S. Dept. of the Interior.
[3]Not more than 1/15,000 of cargo capacity could be discharged at sea.
[4]U.S. Coast Guard Pollution Incident Reporting System data for 1970.
[5]Beynon, L. R. 1971. Report on oil spill statistics at Milford Haven. Exhibit 48, U.S. Dep. Int. hearings, Trans-Alaska Pipeline, Feb. 1971, Anchorage, Alaska.
[6]Covers all casualty losses, including these in open ocean for 1969-70.
[7]Incomplete, no open ocean amount included.

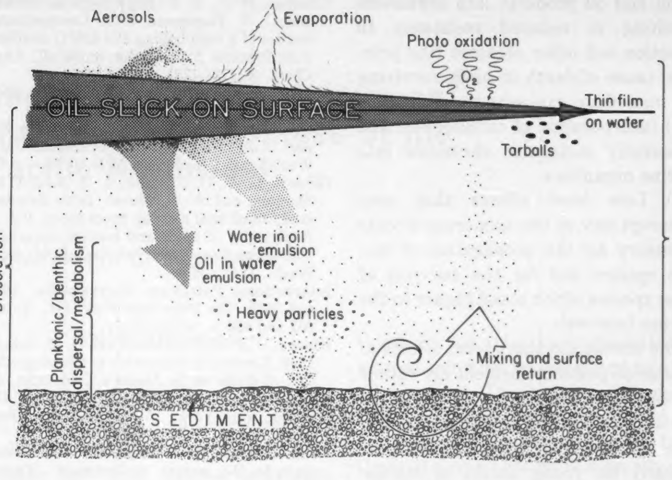

Figure 2.—Diagrammatic summary of the processes leading to the distribution and consumption of petroleum at sea.

of petroleum spilled at sea is dependent upon one or more of the following processes (Butler, Morris, and Sass, 1973):

1) Evaporation and decomposition in the atmosphere.

2) Dispersal in the water column as dissolved or particulate matter.

3) Incorporation into sediments.

4) Oxidation by chemical or biological means to carbon dioxide.

BIOLOGICAL FATE OF OIL

Neither a single rate nor a mathematical model for the rate of petroleum biodegradation in the marine environment can be given at present. On the basis of available information, the most that can be stated is that some microorganisms capable of oxidizing chemicals in petroleum have been found in virtually all parts of the marine environment examined.

Laboratory experiments have demonstrated that the *n*-alkane fraction of petroleum is most easily degraded by microorganisms. In oxygenated marine environments, this type of compound is likely to be degraded in a matter of days or months, depending principally on temperature and nutrient supply. Other classes in petroleum tend to show a greater resistance to microbial action, and considerable lengths of time may be required for substantial decomposition of the extremely resistant components of petroleum in the marine environment—although such refractory components may not be biologically important.

In larger organisms, hydrocarbons are taken up through the gills, by ingestion of food or other particulate matter, or directly from water which passes through the gut. The first two pathways have been demonstrated. Some organisms (e.g., copepods) can ingest large quantities of petroleum and eliminate it directly as fecal matter without substantial degradation. Metabolism of petroleum hydrocarbons in marine organisms and pathways are poorly understood.

Storage of hydrocarbons, including some of those from petroleum, has been found in the lipids of some organisms but its importance as contributing to environmental stress has yet to be established. Biogenic hydrocarbons, particularly di- and triolefins, are clearly distinguishable from petroleum in most cases, while certain saturated and aromatic hydrocarbons have been found to accumulate during short exposure periods with subsequent discharges or loss of the contaminant from the organisms.

Many organisms (e.g., mussels and oysters) can eliminate most of their incorporated petroleum hydrocarbons if placed in unpolluted water. Discharge by vertebrates occurs primarily through the gall bladder and kidney. Paths of discharge for invertebrates are not well established. There is no evidence of food web magnification in petroleum hydrocarbons in the marine environment (National Academy of Sciences, 1975).

DIRECT EFFECTS ON FISHERIES

If large-scale petroleum hydrocarbon pollution occurs in the northeastern Pacific Ocean, the direct effects on fishery species of commercial and recreational value and their food webs can include: 1) direct poisoning; 2) disruption of the marine ecosystem, habitats, and food chains; and 3) general reduction in productivity of the environment on both short- and long-term bases. These biological effects could in turn be related to potential impacts on the commercial and recreational fisheries—resulting in reduced catches, unmarketable catches, or the closure of fisheries due to oil pollution. In addition, benefits from recreational and commercial fisheries could be reduced locally by the 1) physical effects such as gear losses, removal of historical fishery grounds by petroleum-related structures, and interruption in fishing activities caused by tanker traffic, and 2) the diversion of capital and labor force from fisheries and marine recreational development into investment opportunities associated with pipeline construction and operation.

In perspective, large quantities of tanker-carried crude petroleum has been transported along other U.S. coastlines without major environmental degradation to ecosystems, although the impact on some localized shorelines is now being felt—such as tar on Florida bathing beaches and the almost annual spring occurrence of weathered oil residues on the open beaches of the Pacific Northwest. When they occur, the potential biological and physical effects of marine transportation in the northeastern Pacific Ocean will probably be most severe in the coastal and estuarine environments near the terminal areas of the tanker routes. The magnitude of the effects on the recreational and commercial fisheries would depend on the amount of pollutant; the type of pollution (chronic low-level or large isolated spills); the success of prevention and cleanup of both chronic and acute oil pollution; the location, the season, and the frequency

of acute losses from vessel operations; and accidents.

A large oil spill could dramatically affect the fishing and aquaculture industries, whose success depends on clean water. The U.S. Department of the Interior estimates that commercial fishing has an annual whosesale value of about $24 million within Prince William Sound, Alaska; and considerable sport fishing also occurs there. The estimated annual commercial and sport fisheries for the greater Puget Sound Basin is of the order of magnitude of $75-85 million; the value for recreational fishing has been placed at about two-thirds of this figure. Recent efforts in aquaculture have shown considerable success and are predicted to add an additional $100 million in the forseeable future (Flajser and Wenk, 1972).

The short-term (in a geological time frame) use of the ocean for vessel traffic during the duration of the pipeline system has a potential for affecting the long-term productivity of the marine ecosystem as well as a possible short-term impact on the industries that are dependent upon a productive ecosystem. Unlike oil and gas, food from the sea is a renewable resource that can be utilized most efficiently so long as the water quality is sufficiently high to allow fish and plant life to enjoy sustained growth, combined with scientifically sound harvesting techniques and global fishery policies.

POTENTIAL EFFECTS OF OIL POLLUTION ON MARINE RESOURCES

Blumer (1971) summarized the potential damage to marine ecology from pollution with crude oil and oil fractions based on isolated field and laboratory studies as follows:

1) Direct kill of organisms through coating and asphyxiation.

2) Direct kill through contact poisoning of organisms.

3) Direct kill through exposure to the water-soluble toxic components of oil at some distance in space and time from the accident.

4) Destruction of the generally more sensitive juvenile forms of organisms.

5) Destruction of the food sources of higher species.

6) Incorporation of sublethal amounts of oil and oil products into organisms resulting in reduced resistance to infection and other stresses (the principal cause of death in birds surviving the immediate exposure to oil).

7) Incorporation of carcinogenic and potentially mutagenic chemicals into marine organisms.

8) Low level effects that may interrupt any of the numerous events necessary for the propagation of marine species and for the survival of those species which stand higher in the marine food web.

The immediate short-term effects of a major oil pollution incident are rather obvious. However, some of the more serious aspects of oil pollution may deal with the low-level toxic effects, particularly on young forms of marine animals, which might result in potentially dangerous situations which could adversely affect our fisheries resources.

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MFR PAPER 1220

Impact of Cooling Waters on the Aquatic Resources of the Pacific Northwest

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INTRODUCTION

Aquatic animals, with the exception of aquatic birds and mammals, are cold-blooded or poikilothermous, which means that their internal body temperature approximates that of the environment in which the animal lives. Since the aquatic environment has a comparatively narrow range of temperature, fish and shellfish do not have wide temperature tolerances. They can never adjust their body temperature below or above that of the surrounding water; therefore, they suffer damage or death from temperatures higher or lower than their normal temperature range. In addition, the life processes, growth, and activity of cold-blooded animals are governed by the temperature of their environment.

The following discussions are related solely to the effect that man's industrial activities, especially electrical power generation, have or may have on the temperature of the aquatic environment of the Pacific Northwest area and the subsequent effect of these alterations on the aquatic biota.

The demand for electrical power in the United States generally, and in the Pacific Northwest specifically, is increasing at an alarming rate. The Bonneville Power Administration (BPA) of the U.S. Department of the Interior estimates that the firm energy sources in the Pacific Northwest will almost triple in the next 20 years. Since most of the economically feasible hydroelectric sites have already been developed, the bulk of the new power will be from thermal generation, both nuclear and fossil fuel, such as coal and oil.

Thermal nuclear power generation is very inefficient. Approximately two-thirds of the total heat generated is wasted and must be dissipated into the environment. This has caused concern for the aquatic environment and its biota since the waste heat from thermal electric plants is normally disposed of in rivers, lakes, estuaries, and the sea. A 1,000-megawatt thermal nuclear plant, with once-through cooling will discharge as much as 2,000 cubic feet per second of water heated an average of 19.4°F (10.8°C) above the ambient temperature in fresh water and 25°F (14°C) in salt water (Coutant, 1970). Little is known of the effects that the addition of such tremendous amounts of heat would have on marine resources. The major indigenous fishery resources of the Pacific Northwest are both cold-water and anadromous species. This creates special concern for their welfare with the advent of widespread thermal pollution in the aquatic environment. This report describes the present and predicted future sources and volumes of cooling waters returned to the marine environment in the region; it reviews the physical and biological effects that such cooling water may have on the marine resources.

SOURCES OF COOLING WATER

Present Sources

The Pacific Northwest has obtained almost all of its electric energy from hydrogeneration up to the present time. There are 161 hydroelectric projects in the region (Bonneville Power Administration, 1972). Because of a limited supply of alternate energy sources and a generous supply of hydropower, the Pacific Northwest has used electric energy at an even greater rate than the rest of the nation. However, most of the feasible hydropower sites have been developed, and the region's electrical suppliers are turning to steam electric generators, mostly nuclear fueled.

Each of the different methods of generating electricity has harmful as well as beneficial effects on the environment. Hydroelectric development, in the past, has blocked or otherwise hindered anadromous fish runs, in addition to inundating spawning areas. However, it has benefited the fisheries by controlling floods and releasing additional water during the low-flow periods in the late summer and fall. Steam-electric plants—particularly those that are nuclear-fired—return great quantities of heated water to the environment. Laboratory and on-site experiments have shown this to be detrimental to the aquatic life in the immediate area of the discharge. On the other hand, experiments have shown certain instances where heated water at safe levels has induced greater productivity and growth rates of aquatic animals (Bell, 1971).

There are numerous sources of thermal pollution in the waters of the Pacific Northwest, mainly around large metropolitan and industrial areas. These probably vary from purely heated water to a multitude of combinations of heated water with other pollutants. A survey of the lower Columbia River revealed 19 thermal pollution outfalls between Bonneville Dam and the mouth of the river. It was calculated that these outfalls put sufficient heat into the river during the summer to raise the temperature of the entire flow by 0.5°F (0.3°C). The shore water where the outfalls are usually located could be expected to increase more than 0.5°F.

The largest single source of manmade heat injected into the Columbia River comes from the Washington Public Power Supply System plant at Hanford, Wash. It was the largest thermal nuclear plant in the United States when it went into production in 1966 and it was the first in the Pacific Northwest. The electrical power produced at this plant requires the diversion of 1,240 cubic feet per second of cooling water from the Columbia River. This quantity of water diverted daily from the Columbia River was more water than used daily for domestic purposes in the entire state of Texas and twice the daily domestic consumption of the entire city of Los Angeles (Snyder, 1969). This volume of water is increased by 30°F (17 °C) over normal river temperatures as it is pumped through the condenser of the plant. The effluent cooling water from the Hanford plant is discharged into the mainflow of the Columbia River.

The only other large thermal electric plant operating in the region is the huge new fossil fuel plant at Centralia, Wash. It apparently does not contribute substantially to thermal pollution of the aquatic environment because it has cooling towers, and most of the heat is discharged via the towers into the atmosphere.

Most of the thermal power generation in tidewater on the west coast is in California where in 1968 there were 2 nuclear and 21 conventional plants; Oregon had 7 conventional plants and Washington only 3 (North and Adams, 1969).

Future Sources

As mentioned earlier, most of the economic hydropower resources will soon be developed and some authorities believe that by the early 1990's hydropower resources will be used to serve peak demands and thermal plants will operate as baseload plants. Figure 1 (Bonneville Power Administration, 1972) depicts the future dependence on thermal electric power in the Pacific Northwest. A hydrothermal program developed by BPA to meet the predicted demand for electricity calls for the construction of 20 thermal plants in this region by 1990 (Bonneville Power Administration, 1969). If these plants used once-through cooling, it would mean that approximately 32,000 cubic feet per second of cooling water would be returned to the environment at 18°F (10°C) above ambient. A volume of 32,000 cubic feet per second is approaching one-half of the low flow of the Columbia River. This volume of heated water could obviously have far-reaching effects on the environment.

The search for sites to locate the thermal nuclear plants has concentrated on the Columbia River, the

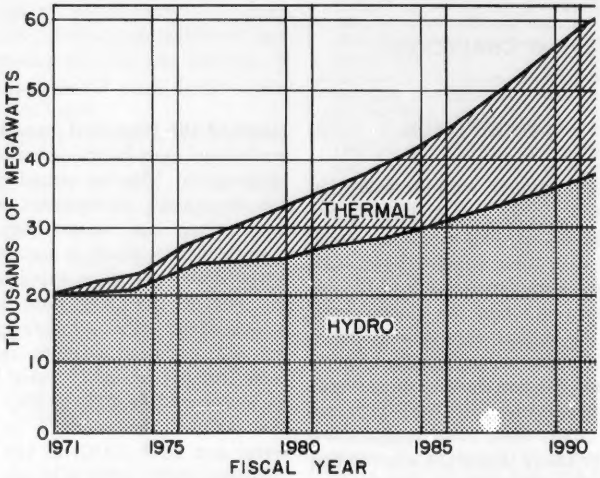

Figure 1.—Predicted future dependence on thermal electric power in the Pacific Northwest (Bonneville Power Administration, 1972).

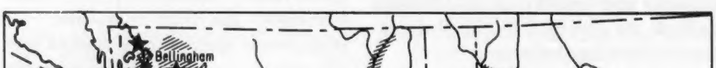

Figure 2.—Proposed location of thermal electric power plants in the Pacific Northwest. (From Snyder, 1968.)

coasts of Oregon and Washington, the Strait of Juan de Fuca, and Puget Sound (Fig. 2). However, possible sites for nuclear power plants have included northwestern Montana and southeastern Idaho (Battelle Northwest, 1967). It would be economically advantageous to locate the plants close to the major centers of industry and population, but many factors, especially the availability of cooling water, will govern the location of plants.

The Trojan Nuclear Plant at Prescott, Oreg., is scheduled to go into operation in 1976. Studies at the site by the National Marine Fisheries Service established that once-through cooling would be detrimental to anadromous fish runs of the Columbia River. To alleviate the problem, the builders (Portland General Electric, Eugene Water and Electric Board, and Pacific Power and Light) included a closed cycle, natural draft cooling tower which will essentially eliminate returning large quantities of hot water to the river. Figure 3 shows this very expensive structure. A similar plant is contemplated across the river at Kalama, Wash.; other nuclear plants are scheduled for construction on the Skagit and Chehalis rivers in Washington.

Floating offshore thermal nuclear power plants are a real future possibility (Russell, 1974). Two plants proposed for 3 miles off the coast of New Jersey will generate 1,150 megawatts each and pump 2 million gallons of cooling water per minute, heated 17°F (9°C), back into the sea. Offshore floating-nuclear-power plants (OFNPP) may be an answer to the lack of suitable onshore generating sites where adequate cooling water is available. Of course, a major question regarding the proposed OFNPP's concerns the effect they would have on the marine environment and resources.

PHYSICAL EFFECTS OF COOLING WATERS ON THE AQUATIC ENVIRONMENT

Temperature affects many physical properties of water including density, viscosity, vapor pressure, and solubility of dissolved gases. Both density and viscosity decrease with increased temperature which accelerates settling velocities and has an effect on the deposition of sediment and sludge in rivers, reservoirs, and estuaries.

Slight differences in density may cause stratification in bodies of water, inhibiting vertical mixing and oxygen transfer to lower waters. Sufficient oxygen is one of the basic requirements for most living organisms. The solubility of oxygen decreases with increasing temperature and may result in oxygen levels less than optimum for a healthy aquatic environment. Atmospheric nitrogen, which is not normally important to good water quality, may reach supersaturation through rapid warming or pressure reduction, as occurs in condenser systems, causing serious problems to fish. Increased temperature also increases the rate of chemical or biochemical reactions and, in the presence of biodegradable organic material, the biochemical oxygen demand may be so great as to deplete the oxygen supply.

Fast flowing streams or rivers have advantages over lakes or reservoirs in disposing of cooling waters. They rapidly transport heated water away from outfalls, minimizing temperature buildup at the discharge point. The turbulence eliminates stratification and makes the exchange of heat between the surface and the atmosphere more rapid. Surface exchange coefficients (U_c) for lakes are about 100 Btu (British thermal units)/ft^2 · day · °F (temperature difference between air and water). Impounded reaches reaches of the Columbia River have U_c values of 130 to 160, whereas values for swift-flowing reaches are from 200 to 300 (Battelle Northwest, 1967). Heat added to a river may be dissipated twice as fast from a swift-flowing section as from an impounded section. Calculations indicate that 85 percent of a 1°C (1.8°F) increase would persist 204 miles downriver in the summer but

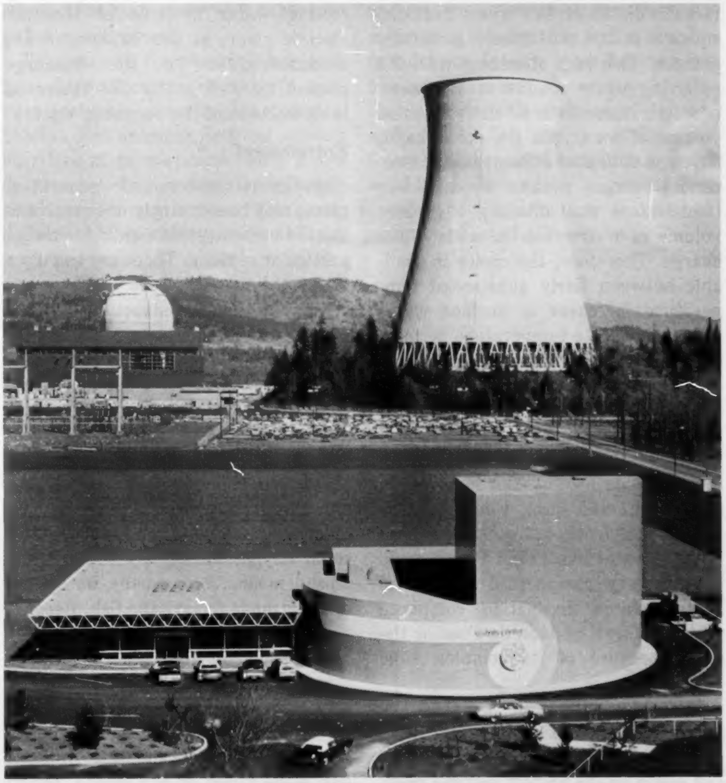

Figure 3.—The Trojan thermal nuclear electric power plant and natural draft cooling tower on the Columbia River (Portland General Electric Company, 1975).

only 65 percent would persist in the winter. It is difficult to generalize how long heat will persist because surface area, time, and current velocity all enter into the exchange process and each should be considered.

In a deep lake or impoundment, the water is usually stratified. In the summer the cool stagnant water of the bottom is separated from the warmer water of the surface by the transition zone. Heated water added to the surface will spread out in relatively thin layers (3 to 6 feet deep) over a larger and larger area until its density approximates that of the surface water. Very little of the effluent will reach the bottom until the fall of the year, at which time, the lake's stratification is broken and the waters mix.

The dissipation of heat from nuclear power plants is estimated to require about 2,000 acres of lake or impoundment surface for each 1,000 megawatts. Cooling water discharge to the surface of the receiving water generally remains on the surface where heat dissipation to the atmosphere is usually greater. This lack of mixing with the receiving water results in high temperature increases in a relatively small volume of water. On the other hand, diffusion of heated effluent into the receiving water results in a lower temperature rise affecting a greater volume of water than in surface discharge. Therefore, the choice is available between fairly substantial temperature increases in surface water versus moderate temperature increases in a much greater volume of the receiving water. The preceding would also be true of a saltwater installation with the exception that the pattern of heated waters would be much more complex because of the periods of flood, ebb, and slack tides and the intrusion of fresh water. An enclosed body of water like Puget Sound could have a very complicated pattern of heated water dissipation compared with the Strait of Juan de Fuca or the ocean because of its complex tidal patterns.

Heat dissipation in estuaries is complicated by the natural stratification caused by the intruding wedge of salt water on the bottom and the fresh or brackish water on top which would be reinforced by the addition of heated water. Although the general movement of the water would be seaward with the flow of the river, there would be the added complexities of the tidal cycle.

Dissipation of heated water at a marine site depends on many things, including ambient water temperature, air temperature, tidal currents, freshwater influx, and plant intake and discharge arrangements. In general a 2,000-megawatt plant (many are planned) will affect the immediate area of a plant to a radius of 6,000 yards. Beyond this point the temperature difference would be too low to maintain stratification (less than 3°F (2°C). Each plant and site is a special case and generalizations are of questionable value, but fairly accurate predictions of the thermal regime expected at a particular site may be made (Adams, 1969).

BIOLOGICAL EFFECTS OF COOLING WATER

Marine organisms are affected by cooling water systems of thermal-electric plants at the intakes, in the condensers, and in the discharge system as well as by the increased temperatures of the receiving waters.

Entrainment

Intake structures of generating plants may be extremely destructive of fish life under certain conditions and at particular seasons. There are usually a series of gates, trash racks, and screens at an intake structure, grading from coarse (to eliminate heavy debris) down to fine screen of 3/8- or 1/4-inch mesh to exclude finer particles that could block the 1-inch diameter condenser tubes. Fish may be impinged and injured or killed at any one of these, depending on the size of the fish and the velocity of the water at the structure. Impinged fish and debris are removed periodically by some mechanized means, but usually no special effort is made to save the fish. Records to assess the true loss of fish caused by impingement at generating plants are few but those that do exist demonstrate the magnitude of the problem. At a generating plant on the Hudson River in New York, almost 1½ million fish were killed in a 2-month period during the winter of 1969-70 (Edsall and Yocom, 1972); the testing of two new pumps at this plant killed so many fish in one month that the operating company was fined over $1½ million (Sport Fishing Institute, 1972a). Impingement takes it toll of aquatic organisms in either the freshwater or marine environment and could be a serious problem wherever thermal electric plants are built.

Myriads of important marine organisms are too small to be screened from the condenser cooling system. They include: fingerling fish, fish eggs and larvae, eggs and larvae of invertebrates, and the balance of the zooplankton that comprises important members of the marine food chain. These small organisms are carried through the condenser cooling system where they encounter many adverse conditions: collision with the internal surfaces, extreme temperature shock, pressure and temperature changes causing gas embolism, and toxic chemicals used as biocides. Several studies have been made of the survival of fish eggs and larvae in condenser systems, almost all of which indicate a high loss. At a thermal nuclear plant in Connecticut, up to 80 percent of the entrained larvae died in passage through the condenser cooling system and none survived passage through the condenser and discharge canal when discharge temperatures were 86°F (30°C) and above (Marcy, 1971). Similar results were experienced at plant after plant where studies have been made of survival of larval fish entrained in cooling systems (Marcy, 1973). Striped bass, menhaden, whitefish, herring, and smelt larvae have suffered heavy losses through entrainment. Losses similar to those mentioned above could be expected at plants in the Pacific Northwest having once-through cooling; many of the same or similar species are present, in addition to Pacific salmon, genus *Oncorhynchus*. Salmon fingerlings, especially pink, *O. gorbuscha*, and chum salmon, *O. keta*, would be vulnerable to power plant entrainment since they migrate in dense schools near shore where intakes may be located.

Distribution

One of the obvious biological effects of power plant discharges of waste heat in other parts of the country has been a

local alteration in the seasonal distribution of fishes. It is a natural tendency for aquatic organisms to seek the temperature where growth and other life processes are at an optimum. Therefore, they may seek cool water in the summer and warm water in the winter. Elevated temperatures in discharge areas may collect numerous species of warm water fish in summer while repelling cold water species. In winter, when effluent temperatures may be tempered by lower river temperatures, all species may be attracted.

Most fish are able to adjust to or avoid temperature changes if they are gradual. However, the operation of power plants can cause both rapid increases and decreases of temperature in the vicinity of the discharges. Reversing the flow through condensers to remove fouling may cause sharp temperature increases, killing fish in the discharge area. Plant shutdowns in winter may expose the collected fish to equally lethal cold-water shock. These disasters have befallen manhaden, anchovies, bluefish, striped bass, and herring—species similar to those in this area. Fish kills as great as 25 tons per month have been estimated for the plants operating between San Diego and Ventura on the California coast. Although some of these problems may be moderated in Puget Sound and coastal locations in the Pacific Northwest because of a more stable year-round water temperature regime, serious loss of fish could result. It has been found that the fully marine and sublittoral species are less tolerant of high temperatures than estuarine or intertidal forms.

Temperature Tolerance

The chemical and biochemical processes of an animal's body accelerate with increasing temperature; normally the metabolic rate doubles with each 19°F (11°C) increase. As temperatures rise, an animal's respiration rate increases along with the heartbeat rate, which consequently increases the demand for oxygen. At higher temperatures the hemoglobin of the blood has reduced carrying capacity for oxygen. The combination of increased demand for oxygen and decreased efficiency for obtaining it causes a severe stress on the organism. This may eventually cause death or one or more of the many sublethal effects.

Several extensive bibliographies on the effects of increased temperatures on aquatic organisms have been prepared (Naylor, 1965; Kennedy and Mihursky, 1967; and de Sylva, 1969). Much of the work is concerned with freshwater rather than marine life, but one recent report has compiled a schematic representation for thermal requirements for different life processes of Pacific salmon (Fig. 4).

The upper and lower lethal temperatures depend on the temperature at which an organism has been acclimated. There are, of course, upper and lower limits above and below which an organism is unable to survive, regardless of acclimation (Brett, 1956). Temperature acclimation and thermal tolerance information is useful in many ways, but it does not provide information on the condition of the organism before it reaches the lethal temperature or of the irreversible physiological effects that may occur well below the lethal temperature.

Tolerance to temperature increases may depend on an organism's geographical range as well as its ecological habitat. For example, tropical animals may live at temperatures only a few degrees below their death point, while arctic species may normally live many degrees below their upper thermal death point. Adult Arctic fishes can usually be acclimated to temperatures far above their normal temperature, whereas tropical species ordinarily cannot be acclimated to temperatures much higher than their normal temperatures. Temperate species have generally exhibited a wide range of experimental lethal temperatures.

Gradual acclimation to higher temperatures increases an organism's ability to survive high temperatures but decreases its ability to survive low temperatures. This accounts for the great loss of fish collected by heated water in the winter that are subjected to sudden cold water by a plant shutdown. Most marine organisms seem to be able to adjust to increasing temperatures more rapidly than to decreasing ones.

The natural habitat of a particular species influences its range of temperature tolerance. Estuarine species are normally more tolerant of temperature fluctuations than sublittoral or littoral species since temperatures fluctuate more in an estuary than in the sea. Intertidal species are more tolerant for the same reason. A review of the literature reveals that eggs, larvae, and young fish are generally less tolerant of increased temperatures and would therefore suffer a greater loss because of this and their inability to avoid the heated effluents.

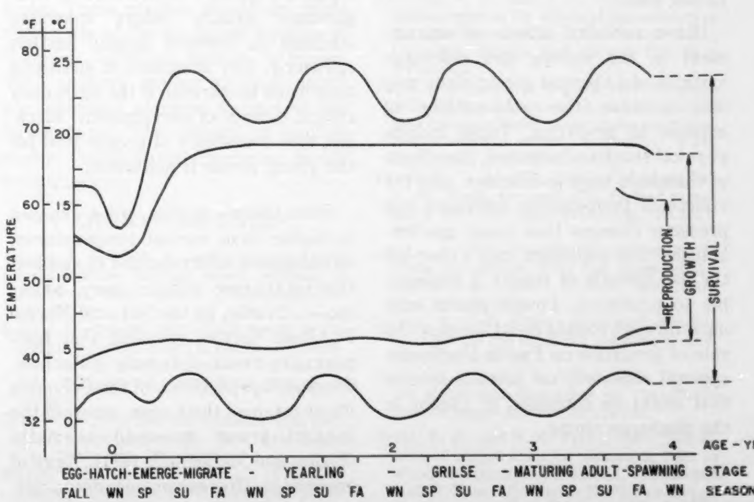

Figure 4.—Thermal requirements for various life processes of salmon. (From Brett, 1970.)

Sublethal Effects

The preceding paragraphs mention the most obvious of the effects that cooling systems and cooling waters have on marine organisms. These are the direct lethal effects where the end result is a dead fish decaying on the beach. The sublethal effects may be even more important, but they are usually much less obvious. These sublethal effects include increased susceptibility to predation and disease; effects on metabolism, growth, reproduction, behavior, the loss and damage of zooplankton; and synergistic effects.

Predation

Increased susceptibility to predation is one of the effects of sublethal exposure to increased temperatures, especially for juvenile fishes. Various researchers have found that a sublethal treatment to increased temperatures caused fry of sockeye salmon, *O. nerka;* yearling coho salmon, *O. kisutch;* juvenile chinook salmon, *O. tshawytscha;* and juvenile rainbow trout, *Salmo gairdneri*, to be all significantly more susceptible to predation than similar individuals not subjected to higher than normal temperatures (Sylvester, $972; Coutant, 1973). The thermal dose necessary to cause this susceptibility to predation was, in some cases, only a fraction of that necessary to cause loss of equilibrium in test fish.

Other sublethal effects of entrainment in the cooling and discharge systems of a thermal power plant may also increase the vulnerability of animals to predation. These include physical shock and abrasion, the effects of chemicals used as biocides, and the effects of temperature increases and pressure changes that cause gas embolisms. Gas embolism may either kill the fish directly or render it susceptible to predation. Power plants with once-through cooling could increase the rate of predation on Pacific Northwest species, especially on juvenile salmon that might be entrained or caught in the discharge plume.

Disease

The incidence of fish diseases (bacterial and parasitic) increases with elevated temperature. This relationship has been observed and studied in hatchery operations for many years. A review of the literature revealed that increased temperature was an important factor in most fish diseases (Ordal and Pacha, 1967). Studies with juvenile salmon and trout demonstrated that increased water temperatures intensified the effects of vibrio disease, kidney disease, furunculosis, and columnaris. Columnaris disease has been found to be exceptionally virulent during periods of high temperature. High temperatures in the Columbia River during the summer of 1941 and the consequent outbreak of columnaris disease decimated the sockeye salmon run that year. The literature is replete with incidents relating high temperatures to serious parasitic and bacterial diseases among aquatic organisms. Although cooling waters probably do not contribute significantly to fish diseases in the area at present, improperly located plants and discharges could cause problems in the future.

Reproduction

Spawning by marine animals may be stimulated by very slight differences in temperature. These changes may be as small as 1° or 2°C for some marine species. Truly oceanic species are usually more stenothermal (restricted to a narrow range of temperature) than estuarine species. A decrease in temperature usually delays spawning whereas an increase usually hastens spawning. Any alteration in spawning time could be harmful if the extremely critical balance of development, hatching, and availability of proper food for the young larvae is disturbed.

Some marine species, when exposed to higher than normal temperatures, do not spawn until returned to ambient temperatures; others may never spawn. Studies by the National Marine Fisheries Service revealed that temperature-treated female eulachon, *Thaleichthys pacificus*, of the Columbia River retained their eggs, whereas the control group spawned normally (Blahm and McConnell, 1971). Eggs of greenlings (*Hexagrammos decagrammos* and *H. stelleri*) subjected to treatments simulating conditions of tidal action and elevated temperatures from cooling waters did not hatch[1].

An increase of 18°F (10°C) could cause temperatures as high as 75°F (24°C) in condenser systems and in confined areas near outfalls in Puget Sound during the warmest months of the year. Very moderate temperature increases have been found to be lethal to Puget Sound Dungeness crab, *Cancer magister*, eggs (Strober and Salo, 1973). An 18°F increase in the cooling water from Puget Sound could cause these lethal temperatures in the condenser system in even the coldest months. Moreover, the eggs of marine species are buoyant and must remain near the surface for proper development. An increase in the water temperature could lower the density to a point where the eggs would sink and not develop.

The intake, condenser cooling, and heated water discharge systems of a thermal power plant could have an adverse effect on reproduction, depending on the proximity to important spawning areas and the life history pattern of the species. Gravid females and their eggs could be damaged by the intake system or by entrainment in discharge waters; spawning time could be altered. Eggs and larvae passed through a condenser cooling system would almost surely be damaged or killed.

Migration

Although few studies have specifically related temperature to the migration of adult anadromous fish, there is evidence that temperature is one of the important factors in the timing of migrations in the Columbia River (Coutant and Becker, 1968). There are records of abnormally high temperatures diverting or delaying migrations of Columbia River salmon (Fish and Hanavan, 1948; Major and Mighell, 1967), and experiments by the Bureau of Commercial Fisheries (now the National Marine Fisheries Service, NOAA) at Bonneville Dam indicated that adult salmon and steelhead preferred ambient or cooler water tem-

[1]Patten, B. G. 1974. High temperature tolerance of eggs and planktonic larvae of the kelp greenling, *Hexagrammos decogrammus*, and white spotted greenling, *H. stelleri*. Unpubl. manuscr. Natl. Mar. Fish. Serv., NOAA, Seattle, Wash., 11 p.

peratures over channels with water temperatures above 70°F (21°C).

Zooplankton

Zooplankton consist of a wide variety of animals, ranging from the smallest protozoa to the eggs and larvae of fishes. The importance of this collection of free floating organisms drifting with the tides and currents cannot be overemphasized. They include the early life stages of most marine species as well as essential food organisms for fishes.

Various studies have been made of the effect of increased temperature and entrainment on zooplankton (Heinle, 1969). Passage through a condenser system may cause mortalities of over 80 percent—if lethal temperatures are reached, and serious sublethal effects may be suffered by zooplankton that survive the passage. Reproductive potential and hatchability of eggs may be seriously reduced.

The mass of zooplankton is astoundingly large. In a study of the distribution and abundance of zooplankton in relation to entrainment in condenser cooling systems in Puget Sound, it was calculated that a 1,000-megawatt plant with once-through cooling could entrain up to 4.5 tons of zooplankton per day during the months of greatest abundance. It was estimated that projected power production on Lake Michigan using once-through cooling would kill 9.8 billion pounds of zooplankton annually. Destruction of this magnitude must certainly have detrimental effects on zooplankton populations.

CONCLUSIONS

It may be concluded that the impact of thermal effluent on the marine resources of the Pacific Northwest is small at the present time. The bulk of the electrical power in the area is from hydropower generation. The only thermal nuclear generating plant in operation is at Hanford, Wash., on the upper Columbia River, and the fossil-fueled steam electric power stations are widely scattered about the area. The Trojan nuclear plant on the lower Columbia River, scheduled to start operation in 1976, will have onshore cooling to protect the environment.

Predictions for future power needs, which will be supplied mainly by thermal nuclear generation, are so great that if once-through cooling is employed, vast quantities of heated water will be added to the area's aquatic environment. The foregoing review of the effect of cooling waters and condenser cooling systems on the aquatic environment and biota make it obvious that the construction of 20 or more thermal nuclear plants in the Pacific Northwest may have a very significant impact on marine resources.

A ruling announced by the U.S. Environmental Protection Agency on 2 October 1974, requires closed-cycle cooling systems on all steam-electric power stations starting operations after January 1974 (Sport Fishing Institute, 1972b). Cooling towers or artificial cooling ponds will be required at most plants to reduce discharge of heated water into streams, lakes, and presumably, bays and estuaries. Apparently the impact has not yet been shown to be great enough to require onshore cooling for coastal plants. It is not clear if this ruling applies to enclosed bodies of salt water like Puget Sound. Once-through cooling in such an area could have an extensive impact on the marine resources and should be avoided.

Extensive physical and ecological studies should be made of any proposed thermal power plant site well ahead of construction to allow adequate planning to minimize the impact of the plant on the marine environment and biota. These studies should be made regardless of the proposed location of the plant—offshore, coastal, or inland. With onshore cooling at most plants and adequate planning to protect the environment, the impact of cooling waters on the marine resources should be minimized.

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MFR PAPER 1221

Effects of Dredging on Aquatic Organisms—With Special Application to Areas Adjacent to the Northeastern Pacific Ocean

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INTRODUCTION

One of the most extensive, noticeable, and controversial of man's activities in the rivers and harbors of the United States is the dredging and disposing of approximately 380 million cubic yards of material each year (May, 1972). The associated cost exceeds 150 million dollars annually (Boyd et al., 1972). Disposal of dredged material is potentially the most important environmental alteration imposed on aquatic resources of our rivers and estuaries. It is becoming an important issue when related to disposal of material offshore. Concern has been expressed by water users, mainly from the standpoint of the real or potential effects on aquatic organisms, water quality, and land use (Montgomery and Griffis, 1973).

The National Water Quality Act of 1969 necessitated the description of environmental impact of construction activities, but it was not until 1973 that the major dredging agencies (primarily the U.S. Army Corps of Engineers) initiated the preparation of Environmental Impact Statements (EIS) for dredging and material disposal programs.

IMPACT OF DREDGING ON AQUATIC ORGANISMS

Background

The Federal agency with the responsibility for maintaining U.S. navigation channels in rivers and harbors is the U.S. Army Corps of Engineers. The Rivers and Harbors Act of 1889 gave the Corps this authority; before that, Congressional authorization was approved in 1824 for the Corps to remove sand bars and snags from major navigable waterways. In Canada, dredging is the responsibility of, and is accomplished primarily by, the Public Works Department, Pacific Region, for the Pacific Northwest area.

Dredging is the excavation of underwater material, usually sand, silt, or gravel. There are three basic processes by which dredging is actually accomplished, i.e., hydraulic or mechanical dredging and a combination of the two. Pipeline and hopper dredging, which use the hydraulic principle, are the most common techniques utilized.

Pipeline dredges are extensively used in the Pacific Northwest for maintenance of navigation channels (Fig. 1). The equipment utilized is basically a barge containing a cutter-head and a suction pipe that is held in position by anchors and lines. An additional pipe floated by pontoons is attached to this basic unit to feed the displaced material to a point of deposition. Booster pumps are needed where long distances from the barge to the discharge point are encountered (O'Neal and Sceva, 1971). The larger the discharge pipe, the greater pump capacity required on the barge. The effluent from the pipeline is usually ponded to develop land fills. Large volumes of material can be moved with this system in a short period of time in water or onshore disposal.

A hopper dredge is a self-propelled vessel (usually ocean-eoing), designed for the hydraulic dredging and the transportation of material to a dumping area. The advantage of the hopper dredge over the pipeline dredge is the ability to operate in rough water and in areas where land fill is not available or

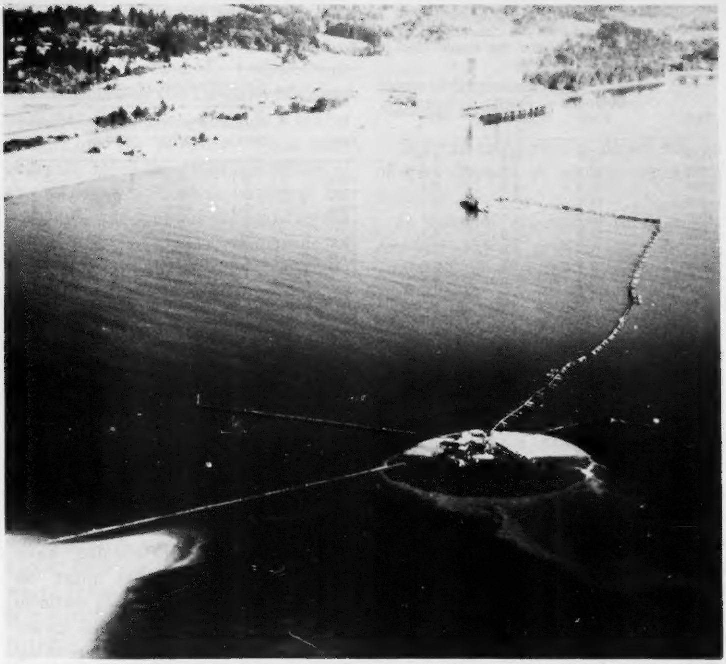

Figure 1.—Pipeline dredge in operation in the Columbia River at Hunters Bar near Kalama, Wash.

desirable. Hopper dredges in the Pacific Northwest vary in capacity from 500 to 3,000 cubic yards. They operate using suction intakes that can be lowered to a desirable depth with scrapers (or shoes) that feed a thin layer of bottom material through the suction pipe into the hopper (Fig. 2). When the hopper is filled, the vessel moves to a disposal site and flushes the material.

Other types of dredges found in the Pacific Northwest include bucket, side-caster, dipper, and ladder dredges. In addition, specially converted vessels are being used to move material through a "propellor-wash" operation (agitation dredging).

Navigation and development are the major reasons for dredging. Channel dredging is necessary to maintain commerce on our nation's waterways and is accomplished on a regular basis within the confines of a specific channel. Offshore dredging is normally conducted to obtain or recover mineral deposits. Normally the material is deposited inshore ("beach nourishment"). Estuarine and inshore dredging are accomplished primarily for channel maintenance, recovery of minerals, and for shellfish operations. The latter apparently has little application in the Pacific Northwest at this time but is of significant proportion in the eastern United States. Size of vessel and deeper draft vessels are increasing the need for the widening and deepening of our waterways. The distance to the entrance of a harbor from the ocean is becoming more important as costs per day of operation for the larger vessels increase. This necessitates the development of deeper ports closer to the ocean. Additional berthing spaces and turning basins are needed for commercial craft. The ensuing construction and development that follow any given port development increase the requirement for new dredging and disposal projects.

Further, the consideration of the exploration and mining of mineral resources from estuaries and offshore

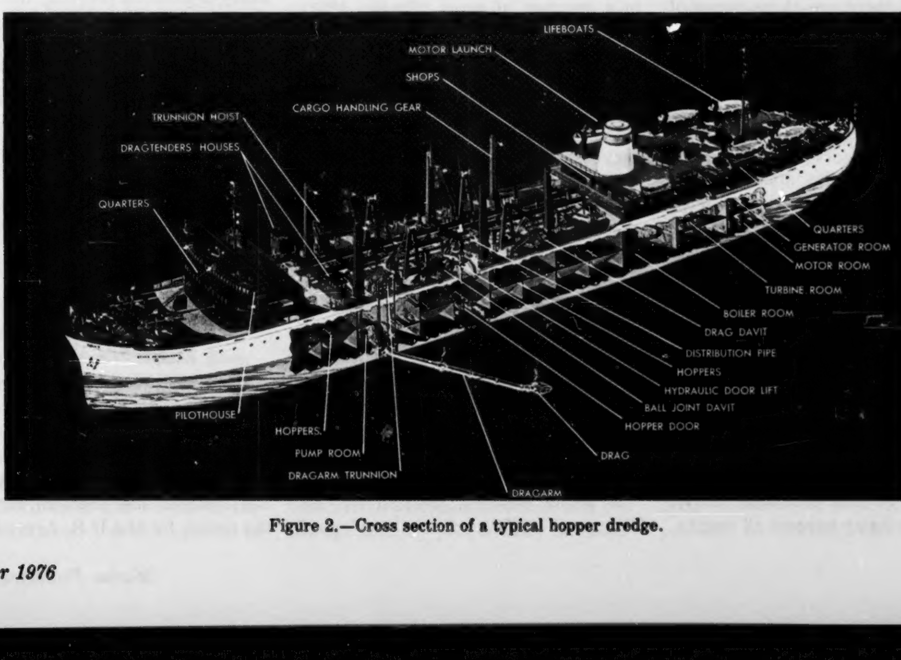

Figure 2.—Cross section of a typical hopper dredge.

areas will increase the demand for material displacement and for a knowledge of the resources that are impacted.

Quantities of Dredge and Disposal Material

Quantities of material that were dredged over a 10-year period from the Columbia and Fraser rivers and the Puget Sound area are shown in Table 1. Dredging on the Fraser River has increased; dredging in the Puget Sound area seems to have remained fairly stable, and the Columbia River dredging varies markedly from year to year. The quantities of material removed average 14.4 million cubic yards annually for the Columbia River and 5.6 million cubic yards annually for the Fraser River; on both rivers, the pipeline dredging method is used to remove most of this material (Table 2). The 14.4 million cubic yards of material dredged annually from the Columbia River would cover over 8,900 acres with 1 foot of material.

Table 1.—Quantities of material in millions of cubic yards dredged from the Columbia River, the Puget Sound area, and the Fraser River from 1964 to 1973.

Year	Columbia River	Puget Sound area	Fraser River
1964	13.6	3.8	4.9
1965	12.2	3.5	5.6
1966	22.4	2.3	5.2
1967	14.1	3.2	5.1
1968	13.7	3.1	5.4
1969	14.2	2.9	5.7
1970	8.7	3.8	5.0
1971	15.4	3.5	6.0
1972	13.3	2.8	6.3
1973	16.5	3.5	6.8
Total	144.1	32.4	56.0
Average	14.4	3.2	5.6

Table 2.—Type and quantity (millions of cubic yards) of dredge activity in the Columbia and Fraser rivers from 1964 to 1973.

	Columbia River		Fraser River	
Year	Hopper dredge	Pipeline dredge	Hopper dredge	Pipeline dredge
1964	5.1	8.5	1.2	3.7
1965	6.1	6.1	1.2	4.4
1966	6.1	16.3	0.9	4.3
1967	4.3	9.8	0.8	4.3
1968	3.6	10.1	1.0	4.4
1969	2.5	11.7	1.2	4.5
1970	4.3	4.4	1.1	3.9
1971	4.3	11.1	1.2	4.8
1972	6.3	7.0	1.2	5.1
1973	6.8	9.7	1.2	5.6
Total	49.4	94.7	11.0	45.0
Average	4.9	9.5	1.1	4.5

General Impacts of Material Removal

Dredging alters the topography of the channel. Between dredging operations, upstream water-borne material gradually restores the river bottom towards its natural shape. Continuous shoaling is the reason for the requirement of continuing programs of maintenance dredging.

In general there are three types of impacts on aquatic resources produced by material removal by dredges: 1) Mechanical effects; 2) turbidity; 3) other miscellaneous effects.

Mechanical Effects

Gutterhead dredging appears to be the type of operation with the most potential for creating adverse direct and indirect effects on the biological communities. This technique is usually utilized to remove loose or hard compacted materials in either new work or maintenance projects. Organisms can be dredged up and physically removed from the area, and the naturally vegetated material is destroyed. It has been shown that most species of aquatic organisms prefer a naturally vegetated bottom (Briggs and O'Connor, 1971). Hydraulic dredging uproots all vegetation, and more than a year may be required for recolonization of aquatic plants (Godcharles, 1971).

Clamshell dredging leaves depressions in the bottom substrate that affect the resource. These holes contain dissolved oxygen and hydrogen sulfide levels that will not sustain fish life or benthic invertebrates (Murawski, 1969).

The removal of benthic organisms by dredging prevents the benthic community from developing its full potential of productivity.

Turbidity and Sediment Effects

A review of the effects of suspended and deposited sediments indicated that sediment loads and deposited material will affect living resources and systems in a number of ways (Sherk, 1971). Turbidity and sediment load of the water column affect primary energy production, which occurs as a result of photosynthetic activities of planktonic algae. Secondary sources of energy conversion in shallow water are other algae, rooted plants, and benthic bacteria. The algae that convert the sun's energy are consumed by small animals adrift in water, or the algae sink and are eaten by bottom dwellers, and so forth through the food chain. However, the primary source of energy is the sun; turbidity can reduce or eliminate production in rivers, estuaries, and the ocean at a time when productivity could be at a maximum.

Miscellaneous Effects

A prime concern, pointed out by Thompson (1973), of the ecological effects of offshore dredging is the change in water clarity and the effects of bottom deposits on larval development and larval settlement. Larvae of bottom-dwelling invertebrates have subtle requirements that must be satisfied before the larvae will settle to the bottom and transform into juveniles. Evidence of the impact of dredging on larval forms of aquatic organisms indigenous to the Pacific Northwest is not available.

In the Pacific Northwest, large volumes of sediments which are high in levels of volatile solids and hydrogen sulfide have been found in major estuaries and bays. When these sediments are disturbed by dredging, the water column contains hydrogen sulfide concentrations that can be lethal to many organisms (Servizi, Gordon, and Martens, 1969). Although the lethal concentration is short-term, the result can be a substantial loss of a year class of indigenous or migratory organisms.

Although there has been concern expressed, little experimentation has been done to determine whether or not high concentrations of potentially deleterious chemicals in the mud are actually released into the water column during dredging in a manner that affects aquatic organisms.

IMPACT OF MATERIAL DISPOSAL ON LIVING RESOURCES

Background

The problem of how to dispose of dredged material is considered to be the number one problem throughout the nation for the U.S. Army Corps of

Engineers. Through the Corps' Waterways Experiment Station, a multi-million-dollar research project has been initiated by the Dredged Material Research Program to provide a better insight into the problem. It has been generally recognized that the impact of the disposal of dredged material far outweighs the problem of removing the material. In any case, thousands of acres of marshland have been lost and are continuing to be lost to various reclamation projects throughout this country. Additional volumes of dredged materials are being placed within freshwater swamps, shorelines, and backwater areas.

The problem compounds itself because deeper and wider channels are being dredged, resulting in the need to dispose of larger quantities of material; disposal sites, however, are becoming harder to locate. This problem is acute where the quality of bottom sediments is undesirable. The problems of material disposal are receiving considerable attention by researchers and in some projects receive high priority funding. In the Pacific Northwest, the Waterways Experiment Station, U.S. Army Corps of Engineers, is funding three research programs directed at finding solutions to the material disposal problems.

Thousands of acres of productive waterways have been lost through disposal of dredged material. Examples of loss of estuarine area due to dredge "spoiling" can be cited for most of our nation's major estuaries. Notable examples on the Pacific coast are in San Francisco Bay and the estuaries of the Columbia and Fraser rivers. The normal technique used in the river is to dredge the channel and place the "spoil" in dikes parallel to the river flow. Then, in subsequent maintenance-dredging operations, the dikes are raised above water level as the first step and filled from the dikes to the existing river bank for the second step. The amount of productive water area lost in the past has not been ascertained for areas of the Pacific Northwest, but the preservation of the aquatic resource requires that it be predicted for the future.

In-channel deposition of material has been resorted to in the rivers of the Pacific Northwest, but the effects on aquatic resources have not yet been assessed.

General Impacts of Material Disposal

General categories of direct effects of spoil disposal on aquatic organisms include:

1) Loss of organisms through incompatibility of dredge and disposal sites; 2) burial of organisms; 3) turbidity; 4) anoxia; 5) toxic chemical release. The impact of material disposal is first seen when the dredging barge or pipeline is moved to a specific dump site and the material is released. Special consideration needs to be given to the environment of the source of the material and the environment of the dump site. More profound impacts can be predicted to occur if the environments are not compatible, i.e., the removal of bottom organisms and material from fresh water or from slightly saline waters and the subsequent deposition in highly saline waters, or the movement of incompatible bottom material from one area to another, which can be disastrous to impacted organisms (Wilson, 1950).

Loss Through Burial

Burial of organisms has been noted as an important short-term impact on the resource; fixed epifauna, such as oysters, perish when covered by sediment (Lunz, 1942). Apparently, some benthic species (primarily invertebrates) reach the surface of newly deposited sediments after burial of more than 20 cm (Saila, Pratt, and Polgar, 1972). Larger and mobile invertebrates have survived burial under as much as 3 feet of material (Westley et al., 1973).

Turbidity and Water Quality

Mechanical or abrasive action of suspended silt and detritus is important to filter feeding organisms with respect to gill clogging, impairment or proper respiratory and excretory functioning, and feeding activity. Moreover, the deposition of suspended materials may interfere with or prevent reproduction by destruction of demersal eggs in upper estuarine nursery areas (Taylor and Saloman, 1968).

High turbidities can and do cause death from littoral suffocation and can disrupt primary productivity and community structure, increasing oxygen demand. There is a wide diversity between the types of materials that are being dredged and deposited and the potential effect on the aquatic resources. In general, the material continually dredged from an active navigation channel in the Pacific Northwest (the Columbia or Fraser rivers) differs markedly in quality from materials dredged from berthing spaces, old turning basins, or near outfalls from industries where pollution may have accumulated over a long period.

Silt loads above 4,000 ppm will prevent salmonids from migrating, while streams with silt averaging between 80 and 4,000 ppm are not desirable for supporting freshwater fisheries (Bell, 1973).

Miscellaneous Effects

Apparently, no far-reaching, long-lasting, or detrimental effects have been seen from the deposition of offshore sediments as beach fill; flora and fauna of beaches are accustomed to change and constant changes are part of the daily pattern of living (Thompson, 1973).

Changes in water quality as a result of large magnitudes of dredged material deposition have received a considerable amount of attention from biological researchers throughout the country (contained in review by Sherk, 1971). Effects on biological systems can be listed as follows: 1) Loss of habitat; 2) decreased euphotic zone depth; 3) increased oxygen demand; 4) increased nurient uptake and release; 5) reduced primary production; 6) community disruption.

The extent and importance of pesticide pollution in estuaries are not fully understood. Chlorinated hydrocarbons that are not of a magnitude to cause damage in specific organisms or constitute a human health problem do pose a threat, however, to other organisms through potential recycling or biological magnification. The potential effect of resuspended sediments containing pesticides and related contaminants is not clearly understood.

Evidence tends to support the contention that nutrient release and possible release of toxic materials occur in the water column with resuspension of bottom materials. This

action could occur during dredging and subsequent material disposal from re-agitation during storms, floods, and beach erosion.

In addition, it has been found that organisms generally accumulate greater concentrations of chlorinated hydrocarbons when they are exposed to turbid waters (U.S. Fish and Wildlife Service, 1970); pesticide concentrations in fish tissues increase with turbidity.

Little information is available on the effect of heavy metals on organisms in the natural state, and levels in most water bodies and their significance are not well known. Trace quantities of heavy metals are known constituents of living matter, but in high concentrations these same metals are highly toxic. Toxicity of heavy metals varies with the presence of phosphorous and nitrogen compounds.

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MFR PAPER 1222

Effects of Dams on Pacific Salmon and Steelhead Trout

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INTRODUCTION

The need for salmon, sea-run trout, and other anadromous fish to spawn in fresh water has made them particularly vulnerable to many of the activities of man. Forestry, farming, road building, growth of cities, industry, and pollution have all taken their toll. However, none of these developments has had more impact on the survival of salmon than the construction of dams. The watershed of the Columbia River presents a critical illustration of the effects of dams on salmon, reflecting events in progress in the entire Pacific Northwest.

The earliest dams in the Columbia River Basin were relatively small. They appeared on tributary streams in the 1840's, constructed to divert water for irrigation, for logging, and for the operation of sawmills. Their numbers were few and their total effect was relatively minor. In the 1880's dams for hydroelectric power were constructed on larger streams, such as the Spokane and Willamette Rivers, seriously affecting the Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*, populations in those streams. In the 1930's major hydroelectric dams were built on the mainstem Columbia River (Fig. 1), initiating the large-scale development of the water resources of the Columbia River Basin for electrical power, irrigation, navigation, and flood control. For the next four decades construction of many large dams proceeded on the Columbia River and its major tributaries producing sudden, enormous changes in the environment of anadromous fish. Great dams barred passage to the sea; huge lakes replaced swift-flowing rivers; spawning grounds were inundated; water temperatures were modified; predator, competitor, and disease relations were upset; food supplies were affected.

The necessity for providing safe passage over the physical obstructions of dams was an obvious reality. Of equal importance was the need to protect the fish when the changes made by dams in the basic environment were too severe. Because there were many dams (Fig. 2) the cumulative effect of small losses, injuries, or delays at each dam became serious. Failure to solve fish passage problems at high dams with large impoundments (i.e., Grand Coulee and Brownlee Dams) resulted in a complete barrier to migrating fish in the upper reaches of the Columbia and Snake Rivers (Fig. 3). This barrier denied, to anadromous fish, access to a substantial portion of the entire Columbia River watershed.

PASSAGE OF FISH

Adult Fish Passage at Dams

As dams were constructed on the Columbia River, fishways were provided to permit adult fish to swim over the dams to continue their upstream migration toward their spawning grounds. These fish "ladders" consisted of a long series of pools (Fig. 4), starting from the water level below the dam (tailrace) and ascending approximately 1 foot in elevation at each succeeding pool until reaching the water level behind the dam (forebay). Water flowed from pool to pool and fish could ascend by swimming over the weirs that separated each pool or through holes in the weirs provided for that purpose.

Although fishways of this general design had been in use for many years, the large scale of fishway construction necessary on the Columbia River and the variety of new situations that had to be faced required more information on fish behavior and abilities than was available.

Some of the questions that needed to be answered were surprisingly simple, such as: At what rate do fish ascend fishways? What is the maximum water velocity through which fish can swim? How does light affect the rate of ascent

Figure 1.—Bonneville Dam, the lowermost dam on the Columbia River, was constructed in 1938. A second powerhouse will be constructed on the north shore (left side), reducing the need to spill large amounts of water.

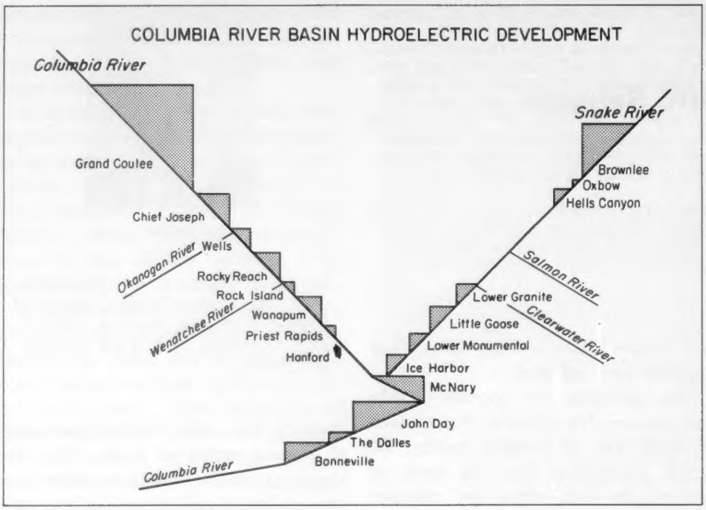

Figure 2.—Diagram showing the sequence of major dams on the Columbia and Snake rivers.

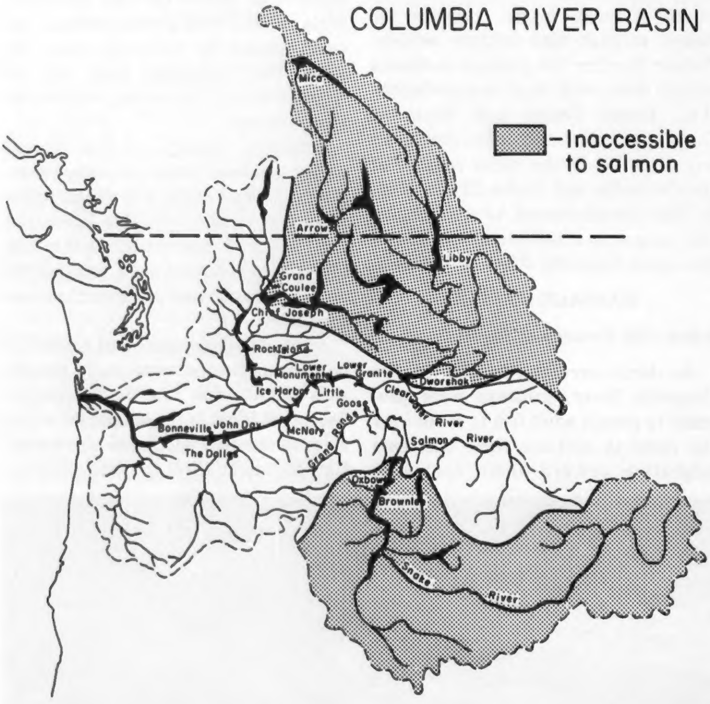

Figure 3.—Areas in the Columbia River Basin no longer accessible to migrating anadromous fish because of dams.

in fishways? Other questions had a direct bearing on the cost of fishways, such as: How large a fishway is needed for a given number of fish? How steep can a fishway be without causing fish to tire or fail to ascend? How long can a fishway be without fatiguing fish? To gain answers to these and similar questions, an intensive research effort was undertaken in which State and Federal fishery agencies, universities, and a major dam constructing agency, the U.S. Army Corps of Engineers, participated.

A special laboratory for fishery-engineering research was constructed at Bonneville Dam in which it was possible to measure the reactions of anadromous fish under controlled experimental conditions while the fish were actually migrating. Fish were diverted from one of the major fishways into the laboratory (Figs. 5 and 6), where their responses to full-scale fishway situations were observed and recorded. Fish then swam out of the laboratory to continue their migration upstream.

Experiments conducted at the laboratory provided data on the spatial requirements of salmon in fishways, on rates of movement of fish ascending fishways, and on the effect of fishway slope and fishway length on fish performance. Scientists measuring both performance and physiological indices such as blood lactate and inorganic phosphate could find no evidence of fatigue from ascending fishways when proper hydraulic conditions were obtained. It was concluded that the ascent of a properly designed fishway was only a moderate exercise for fish, possibly similar to swimming at a "cruising" speed that can be maintained over long periods of time.

Tests to measure swimming abilities (Fig. 7) indicated that the critical velocity of water was between 8 and 13 feet per second (fps). Velocities above this range proved to be an obstacle to a significant number of fish, although some individual fish had a much greater ability. The maximum observed swimming speed was 26.7 fps by a steelhead.

Examination of fish preferences for light conditions revealed marked differences in species. Steelhead, given a choice of light and dark channels, selected a dark channel. Chinook salmon, *O. tshawytscha*, appeared indifferent under the same conditions and moved randomly into both light and dark channels. Steelhead moved more quickly through fishways that were darkened (Fig. 8), yet—in passing through pipes and open channels—showed an increase in speed when light was added. Presented with a choice of

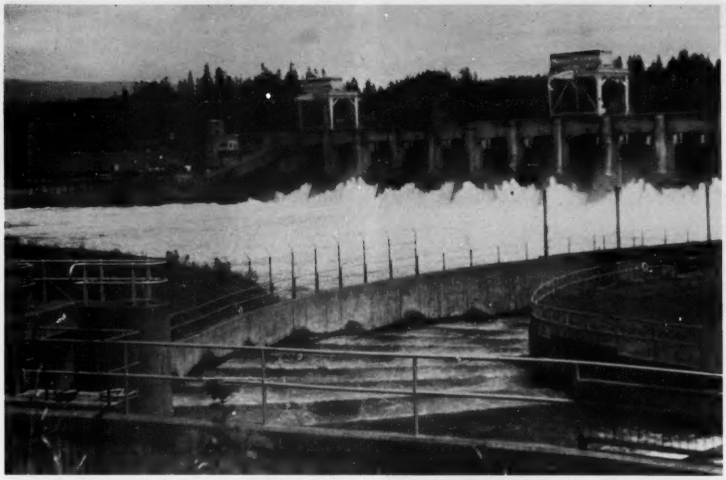

Figure 4.—Pool type fishway (foreground) at Bonneville Dam. The long, windowless building on the opposite shore is the Fisheries-Engineering Research Laboratory.

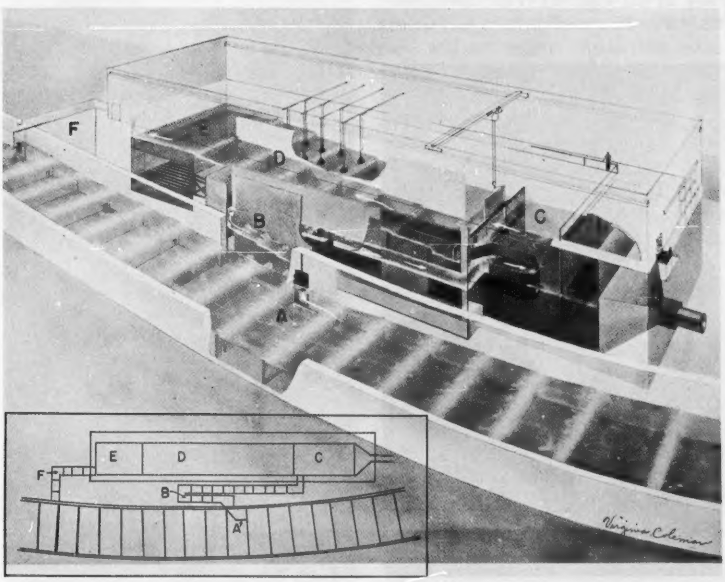

Figure 5.—Sketch of Fisheries-Engineering Research Laboratory at Bonneville Dam showing its relationship to fishway. Fish are diverted from the main fishway by a picketed lead (A) and ascend the entrance fishway (B) to a collection pool (C) in the laboratory. After release they pass through an experimental area (D) to the flow introduction pool (E) and then out the exit fishway (F) where they return to the main fishway. (Insert shows plan view of laboratory.)

channels with a high velocity (13 fps) and a low velocity (3 fps), both salmon and steelhead showed a strong preference for the high velocity.

These are but examples of the types of information gathered at this unique laboratory for use in designing fishways that would be effective and efficient. Full-scale models of complete fishway designs (Fig. 9) were then tested in the laboratory before being put into use at a dam. Even after being constructed at a dam, new fishway designs were carefully evaluated in actual operation (Fig. 10).

The search for information on the behavior of adult fish was also extended into river situations. Individual fish were tracked by means of sonic and radio tags (Figs. 11 and 12) to determine their patterns of movement approaching dams under a variety of flow conditions for improving the design and placement of fishway entrances. Tracking studies of fish movements after leaving fishway exits showed the importance of the proper location of fishway exits because of the possibility of the fish being swept back downstream over the spillway of a dam.

Adult passage at dams is measured at counting stations in each fishway. Trained observers enumerate individual species of anadromous fish as they migrate through the fishway. At some dams migrating fish are directed by picketed leads over a white counting board (Fig. 13) where they can be easily seen and tallied by an observer. At more recently constructed dams, fish counts are made through large viewing windows (Fig. 14) set in the side of a fishway. The data are used in estimating total populations, assessing spawning escapements, and determining effects of changing ecological conditions at dams. Counting is now being done at 12 major dams on the Columbia and Snake Rivers with counting stations in operation from early spring to late fall. When the dam construction phase in the Columbia River Basin has been completed and river flow patterns have been stabilized, however, migrating fish will probably be counted only at a few index dams.

In addition to counting stations in each fishway, most dams have special viewing facilities for the public. The surge of hundreds of thousands of salmon, steelhead, and American shad, *Alosa sapidissima*, passing through the fishways of the Columbia River dams has become a national pride as well as the visible index of the health of a fishing industry and a recreational resource. More visitors come annually to watch salmon and steelhead at the dams on the Columbia River than visit Yellowstone Park or the Grand Canyon (Fig. 15).

Juvenile Fish Passage at Dams

Young salmon migrating to the sea in the Columbia River may have to pass over as many as nine major dams on

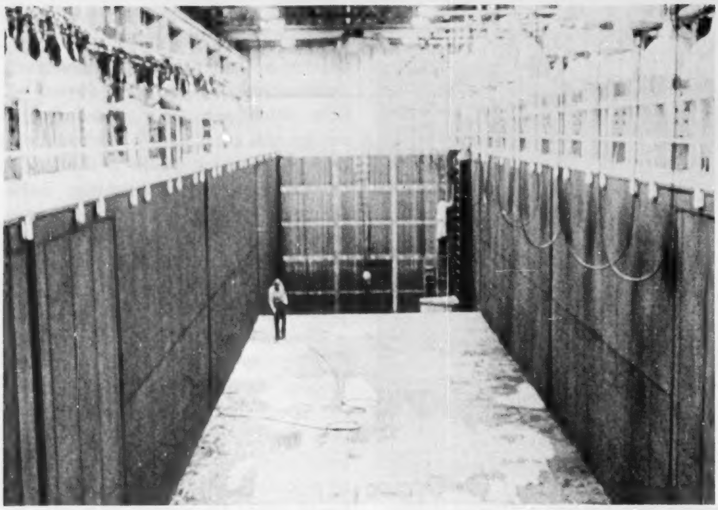

Figure 6.—Interior of Fisheries-Engineering Research Laboratory when empty and unwatered. Experimental area (center) is 104 feet long, 24 feet wide, and 17 feet deep. Fish collection pool at far end is 50 feet long and 24 feet deep.

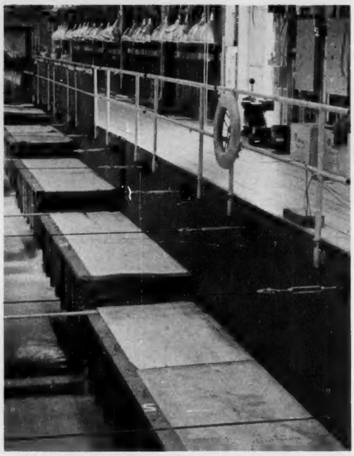

Figure 8.—Covered fishway used in darkened passage experiments. All laboratory lights were turned off during dark tests.

Figure 7.—Experimental channel with a water velocity of 16 feet per second appears on right. Entrance to channel on left is screened to prevent access during swimming ability tests.

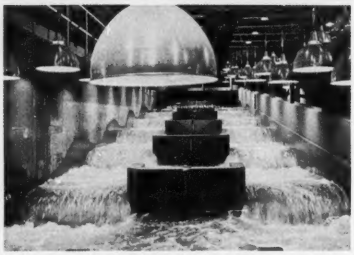

Figure 9.—Test of a full-scale model of a new fishway design in the laboratory.

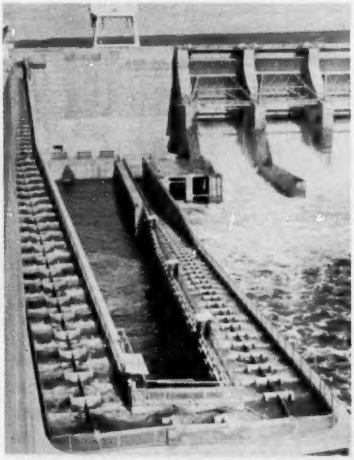

Figure 10.—New fishway design being evaluated at Ice Harbor Dam. Note four observer stations for measuring rates of fish movement.

Figure 11.—Radio fish tag being inserted into the stomach of an adult chinook salmon.

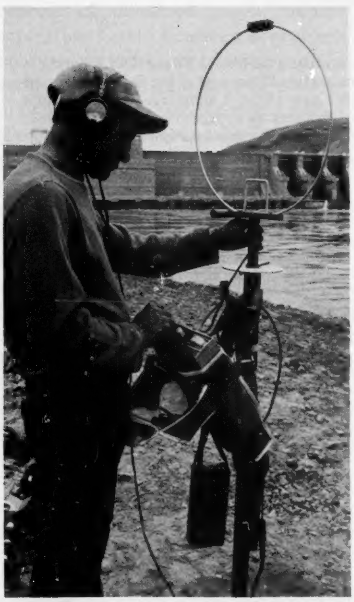

Figure 12.—A fish tracking team member taking a bearing on a radio-tagged salmon below Lower Monumental Dam. Simultaneous bearings taken by two or more team members will be used to establish the location of the fish by triangulation.

Figure 13.—Adult salmon passing over a white counting board which aids observer in identifying species.

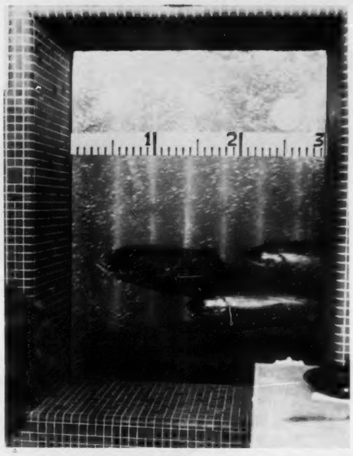

Figure 14.—Adult fish are counted as they pass a viewing window set in the side of a fishway.

their journey downstream. Those that are carried over spillways at each dam pass without injury; those that move with flows through turbines are less fortunate, however. Some are killed outright by turbine blades, high turbulence, shearing flows of high velocity, and sudden pressure changes. Others are injured or temporarily stunned and are easy prey for predators such as sea gulls or northern squawfish, *Ptychocheilus oregonensis*, feeding in the eddies of the tailrace below the dam.

Mortality rates at each dam differ with the relative amounts of water passing through powerhouse and spillway; with the size, species, and condition of the fish; with the type of turbine; with the operating load; etc., but an estimate of 15 percent loss per dam is generally considered to be conservative. With the development of upriver storage reservoirs and increasing water control, a greater percentage of the water (and a higher percentage of the fish) will be passing through turbines so that mortalities might even be expected to increase in the future. These losses are compounded, of course, by the number of dams through which the young fish have to pass.

In response to these critical circumstances, studies were undertaken to develop practical methods of protecting the young migrants at dams.

An investigation of the distribution of young fish in turbine intakes showed that 70 to 80 percent of the migrants were concentrated in the upper 15 feet of water (Fig. 16). The investigation also showed that many of the young migrants entered the gatewell (where the gates that can close off the intake for unwatering the turbine are stored) through a gate slot in the ceiling of the turbine intake. These fish had to leave by the same route or remain trapped in the gatewell. Efforts were focused on a system that enabled the juvenile migrants to bypass the turbines by being diverted through the gatewell and into a passageway leading to the tailrace.

An inclined traveling screen (Fig. 17) was installed that diverted most of the migrants into the gatewell, and holes (labeled "orifice" in Fig. 16) were cut in the gatewell wall, enabling the fish in the gatewell to pass into a channel that connects with the tailrace. This system does not protect all of the migrants entering turbine intakes and it would be expensive to install and maintain in

Figure 15.—"Salmon Watching" at Bonneville Dam.

all of the dams of the Columbia River. It does, however, provide an alternative to excessive mortalities in turbines.

CHANGING ENVIRONMENT OF FISH AND COUNTERACTIVE MEASURES

Dams Bring Change

Vast changes in the environment of salmon have been brought about by the construction of many dams in the Columbia River Basin. Long Chains of lakes now exist where once were rushing rivers, complete with rapids and gravel bars ideally suited for the incubation of salmon eggs. Hundreds of miles of spawning areas were flooded with nearly disastrous effects on fish populations. To replace the loss of so much area critical to salmon reproduction, large scale programs of artificial reproduction were begun by State and Federal fishery agencies. A major share of this effort was begun in 1949 when Congress appropriated funds for the Columbia River Fishery Development Program. This program finances the operation and maintenance of 21 fish hatcheries that produce over 86 million juvenile salmon and steelhead annually in compensation for those that were produced in the wild before dams were constructed.

To fish that had been adapted for thousands of years to existing seasonal patterns of water flow and temperature, the construction of many dams created other environmental stresses. Freshets and floods that had carried young fish swiftly down to the sea were now controlled. In the impoundments behind the dams the water (and the fish) moved more slowly. Research shows that the average impoundment on the Columbia River delayed young migrants about 3 days. Fish from the upper river have been reaching the estuary almost a month later than before the dams were built. This delay in migration through the river extended the exposure of the young fish to hazards such as disease and predation. Temperatures in the river, because of the greater surface area of the impounded waters, increased during the summer at a time when high water temperatures can become critical to salmonids. The habitat of many of the salmon's competitors and predators was increased and improved.

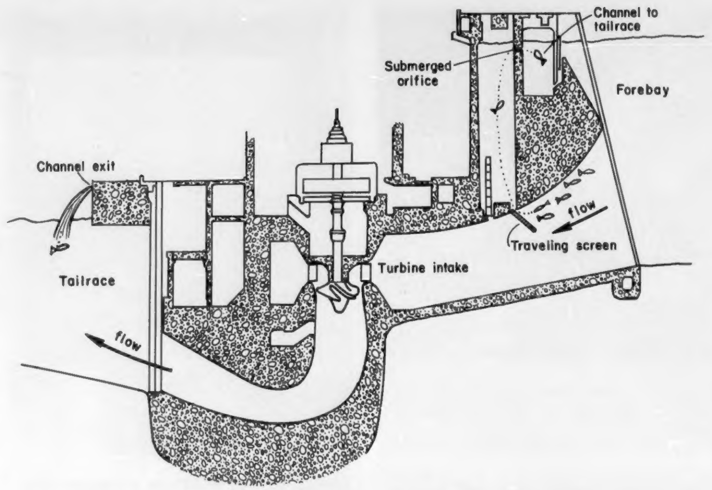

Figure 16.—System to bypass juvenile migrants around turbines. Young fish entering a turbine intake concentrate near the ceiling. Approximately 75 percent of the fish are diverted by traveling screens into the gatewell, then the fish pass through submerged orifices into a channel connected to the tailrace. With this system fish may be bypassed around the turbines of a single dam or the fish may be collected and transported around many dams.

Research on the effects of impoundments on salmon migration showed that the degree of passage success related to the length and volume of the impoundment, to the relative volume of flow through the impoundment at the time of migration, and to both the physical and biological environment in the impoundment. Migration through the impoundments created by the "river run" dams—all about 100 feet high, on the Columbia and Snake Rivers—appears to be generally successful for both adults and juveniles. However, the large impoundments created by dams (i.e., Grand Coulee, 343 feet; Brownlee Dam, 277 feet) proved to be more serious obstacles. Studies made in the Brownlee impoundment showed that while adult fish were able to migrate through the 57-mile long reservoir successfully, the young fish found conditions too severe. A high degree of thermal stratification develops in the reservoir with surface temperatures reaching levels lethal to young salmon while the cooler subsurface water becomes deficient in oxygen. The impoundment, for all practical purposes, is an impassable barrier for juvenile salmon and steelhead.

Figure 17.—Traveling screen shown in operating position on the deck of Little Goose Dam. Hydraulically operated arm is withdrawn to permit lowering of screen through gatewell slot.

Dams are also responsible for creating a condition under which the water becomes supersaturated with gases. Frequently referred to as "nitrogen supersaturation" because air is nearly four-fifths nitrogen, the condition is lethal to fish at high levels of gas pressure. Large volumes of water discharging over a spillway plunge into a deep pool below the dam forcing entrapped air into solution with the water. Under the hydrostatic pressures prevailing at depths of 40 feet or more in the spillway basin, the gases are continually dissolved and added to the water as long as spilling continues. In free-flowing rivers, where riffles and cascades provide for a quick release of dissolved gases, supersaturation rarely becomes a problem because gas pressures in water rapidly return to atmospheric level. In a series of impoundments such as now exist on the Columbia and lower Snake Rivers, there is not sufficient circulation to provide for a rapid release of gases. As a result, gas pressures remain above atmospheric levels.

Fish trapped in supersaturated water suffer from so-called "gas bubble disease." This relates to the physical damage caused by creation of gas bubbles in the tissues and blood vessels (Fig. 18). Dissolved gases are absorbed in the bloodstream and embolisms are formed when the gases leave solution. The symptoms are analogous to the "bends" in human divers when they move too quickly from a high-pressure to a low-pressure environment.

Mortalities created by supersaturation have been high for adult and juvenile fish in high-flow years, in which large volumes of water were surplus to power generation use and were passed over spillways. The most critical circumstances occurred when new dams were completed and a high flow occurred before the turbines could be put into operation. At such times, the entire river flow plunged over the spillway. Saturation levels have reached a deadly 145 percent (100 percent is normal; over 110 percent begins to be lethal to fish).

In an effort to reduce supersaturation, the U.S. Army Corps of Engineers, after an intensive search of alternatives, developed a spillway flow deflector (Fig. 19) that creates a surface flow below the spillway instead of permitting the deep plunging action that is responsible for most of the supersaturation. With the installation of the deflectors at all of the dams on the river, it is hoped that major problems with supersaturation will be solved.

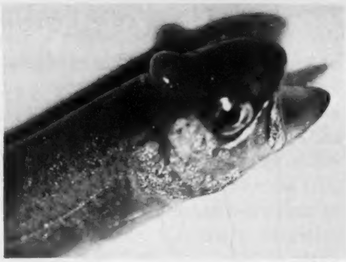

Figure 18.—Gas bubbles beneath the skin on the head of a young chinook salmon. When bubbles burst, infections may set in and kill the fish. Dissolved gases absorbed into the bloodstream form bubbles when the gases leave solution. These embolisms may block the circulatory system and cause death.

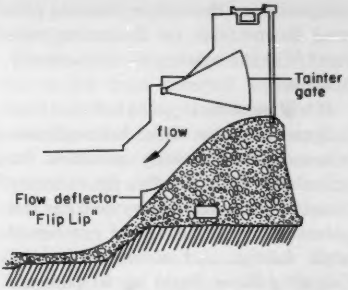

Figure 19.—Cross section of a spillway showing flow deflector (Flip Lip) installed to reduce supersaturation. Deflector creates a surface flow instead of permitting the plunging action responsible for supersaturation.

Collection and Transportation

To avoid the cumulative hazards of a long series of dams and impoundments to upriver stocks of fish, a system is being evaluated that would collect young migrants at the uppermost dam and transport them to the estuary. Under this procedure, losses—from turbines, from predation, from supersaturation, and from other adverse environmental effects in many miles of impoundments—would be eliminated. Collection would be by the use of turbine intake traveling screens and gatewells. Instead of the bypassed fish being released to the tailrace, they would be diverted temporarily into holding ponds, then trucked and released at appropriate locations in the estuary (Fig. 20).

Research is now in progress with fish marked as juveniles by the insertion of a tiny piece of magnetic wire in the snout. Initially some of these fish (test fish) were transported around the dams (Fig. 21); some (control fish) were released to find their way down the long series of dams and impoundments. When these fish return from the sea as adults and ascend the fishway at Little Goose Dam, a detector will recognize the magnetic tag and automatically shunt the fish into a holding tank where they can be examined to determine which treatment they received. When the data are analyzed scientists hope to have the answers to many questions. For example, will the homing of the fish to its native stream be affected by its capture and "rerouting"? What will be the losses associated with collecting, holding, trucking, and releasing fish in

Figure 20.—Tank trucks transport fish from collection and marking area around the hazards of seven dams and six impoundments for release below Bonneville Dam, about 350 miles downstream from Little Goose Dam. Studies are also being carried out at Lower Granite Dam in which eight dams and seven impoundments are being bypassed.

comparison with allowing them to proceed downstream on their own volition? Will the system be economically feasible?

It will be several years before a final judgment can be made, but sufficient information is already available for optimism. Theoretically, by reducing losses of young fish, the system has the potential for increasing the number of adult salmon and steelhead to the Columbia River Basin by 60 percent. The degree to which reality can match this potential remains to be seen.

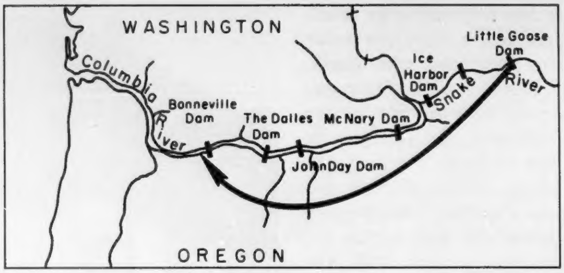

Figure 21.—Transportation route from Little Goose Dam to below Bonneville Dam.

CONCLUSION

Despite the many problems that complicate the maintenance of salmon runs when rivers are interrupted by dams, our runs of salmon can be maintained. Problems of reproduction, passage, temperature, delay, and supersaturation all can be solved if enough effort is made. Even the "impassable" large impoundments can be bypassed. With sufficient determination, there will always be salmon in the "Salmon" River—and all of the other salmon streams of the Northwest.

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MFR PAPER 1223

Effects of Water Diversions on Fishery Resources of the West Coast, Particularly the Pacific Northwest

Blahm

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INTRODUCTION

Man has found it necessary to divert water from its natural courses to enhance his existence and insure his survival. In the United States, for example, the Rio Grande River no longer flows into the sea, and all water of the Colorado River is being used—except for 1.5 million acre-feet, which is allocated to Mexico. The Missouri and Mississippi rivers have been affected by man's water diversion practices. Another example, which has altered the environment of Delaware Bay, is the diversion of Delaware River water to New York City. In 1922 the total water storage capacity in the United States was 33 million acre-feet; in 1962, it was about 300 million acre-feet; and by the year 2,000, an estimated 600 million acre-feet will be stored. By 1980 approximately 50 percent of our stream and river flow will be diverted. By the year 2000, this will increase to more than 80 percent. As we carry out vast programs of water storage and use, we will greatly curtail river flow into the sea (Stilwell, 1962). Even though less than 1 percent of the world's water supply is now diverted or stored (Armstrong, 1972), the manipulation of this seemingly insignificant portion can have a profound effect on the survival of fish species.

In the United States today, the primary water uses are: 1) electrical power production, 2) irrigation, 3) flood control, 4) navigation, 5) industrial, 6) mining, 7) domestic, and 8) recreation. These uses are not listed in order of importance because any one use on any body of water may take precedence over all others; each plays a part in contributing to water diversion problems.

While there are a multitude of examples to demonstrate the biological consequences of diverting water, this paper will outline only the impact on the fishery resources of the west coast.

MAJOR TYPES OF WATER DIVERSION ACTIVITIES

Irrigation, Flood Control, and Navigation

Irrigation, flood control, and navigation are important west coast water uses that affect fish production. Many dams used solely for these purposes have been built without fishways, and portions of the production of Pacific salmon, *Oncorhynchus* sp., have been eliminated by these obstacles.

Irrigation

The Columbia River Basin Project, supplied by pumps at Grand Coulee Dam, has hundreds of miles of main irrigation canals which will transport over 4 million acre-feet of water. Although the main canals are screened to the laterals, the intakes of the large pumps are not screened. In the Columbia River drainage, the U.S. Department of Interior's Bureau of Reclamation has pumping plants and irrigation projects that entail more than 40 significant dams. Extensive irrigation systems have been developed in many of the major Columbia River tributary systems, e.g., Yakima, Boise, Payette, John Day, and the Umatilla. There are nearly 70 private storage and diversion structures in the Columbia River system alone. The Bureau of Reclamation owns or supervises approximately 83 projects in the state of California, all creating comparable problems. The U.S. Army Corps of Engineers has numerous projects in Washington, Oregon, and California; although they are primarily hydroelectric projects, the impounded water can be diverted for irrigation.

Screens, or other structures, that remove fish from diverted water can cause fish mortality; however, if the screening structures were not used, more severe loss would probably occur. Fish screening structures are required when taking water from a river system, but irrigation diversions are often unscreened and young fish are diverted into the farmer's field. Even when screens are installed, they are often removed to provide maximum water flow. These problems occur despite laws and regulations pertaining to the installation and operation of fish screens. The Federal government participated with State agencies in the fishery development of the Columbia Basin under a program initiated in 1949. Within this program over 700 fish screens (Fig. 1) have been installed, most of which were in operation during

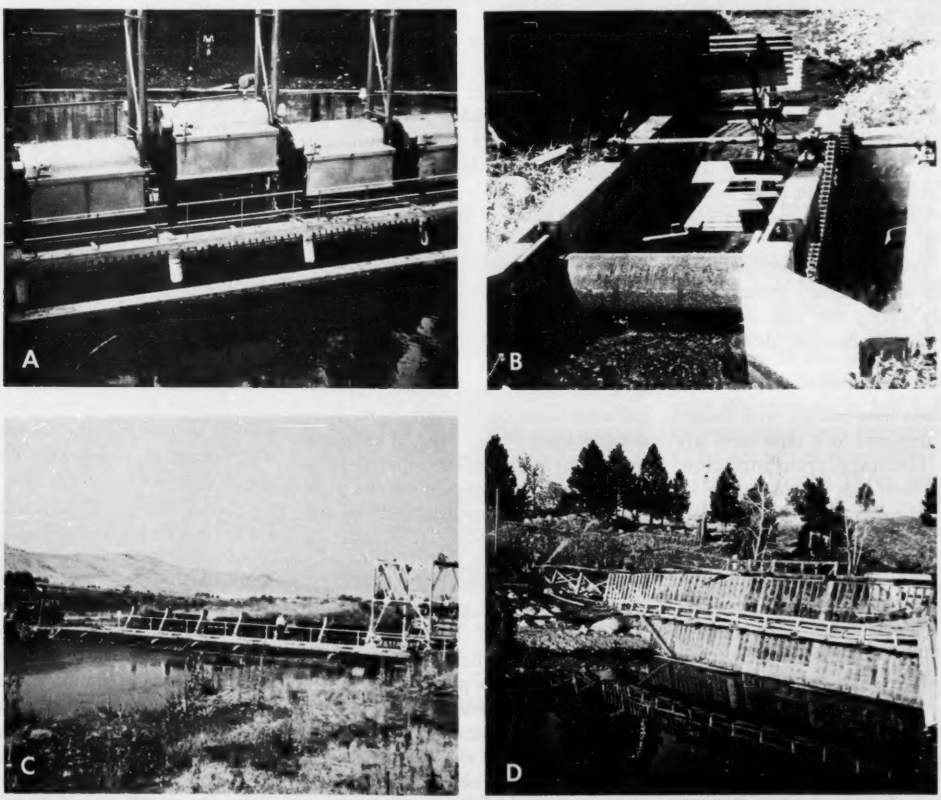

Figure 1.—Fish screening installations in the Columbia River drainage: (A) vertical traveling screens, (B) and (C) two sizes of paddle wheel powered drum screens, and (D) screening weir.

1974. Throughout irrigated lands in the western United States and Canada, there are thousands of such structures, large and small. Each screen-effort can have influence on fish survival by contact mortality, by not screening out eggs and larval fish, and by diverting fish into by-pass canals where predation is increased and water quality is not optimum.

Flood Control

A secondary feature of most water diversion projects is flood control. The Truckee River Project along the border of California and Nevada coordinates water use in the interest of flood control, hydroelectric power, and recreation. During the early development of the project no safeguards for fish were included; this has resulted in a reduction of fish populations. It was reported by the U.S. Fish and Wildlife Service (1950) that there would be 42 diversions on the Truckee River, 5 of which would be for electrical power, the others for irrigation and flood control. It is obvious that fish ladders and screens are required to protect some fish. The San Joaquin River Flood Control Project in California, as proposed in 1958, would destroy fishery habitat and result in large animal losses. Flood control projects can specifically eliminate sloughs, affect littoral vegetation, and inundate deep pools which are necessary to carry over the fishery during the summer (U.S. Fish and Wildlife Service, 1958).

Navigation

Navigation uses conflict with fisheries when dam-and-lock structures are built to facilitate transportation. Spawning beds can be damaged by channel improvements or by direct gouging of stream bottoms. Water level fluctuation can occur when water is released to maintain navigable depths.

Mining and Road Construction

Mining and road construction are important activities in some watersheds. Water, which is diverted for processing excavated materials, is returned to the system—polluted chemically and thermally. Gold dredging has gutted streams, blocked fish migration, and resulted in silting many miles of spawning grounds. In California, several tributaries to Shasta and Deswick reservoirs and the upper Sacramento River contribute heavy metal and acid pollutants which accumulate in waters diverted for mining operations. Chinook salmon, *O. tshawytscha*, and steelhead trout, *Salmo gairdneri*, in the Sacramento system support a fishery estimated to have an average annual value of $1,400,000. It is reported that the food supply of these anadromous fish has been adversely affected, and significant numbers of fish have been killed (U.S. Fish and Wildlife Service, 1959).

The easiest route for a road through rugged terrain is adjacent to an existing stream bed, and consequent desecration of the stream's environment (Fig. 2) will affect its fish populations. In most western States, gravel excavating and processing for road construction is a major activity (Boland, 1974; Miller and Peterson, 1974). Small streams are diverted to allow access to the gravel beds and provide water for washing gravel. During construction of the Alaska oil pipeline from Valdez northward to Prudhoe Bay, more than 500 miles of new road will be built and improvements will be made on existing road beds. One hundred and sixty river and stream crossings will be necessary to complete the road; each crossing will divert water in some way. Precautions can be taken, however, to reduce harmful effects of road construction. For example, many streams will be diverted under the roadway through culverts (Fig. 3); studies have been done on their design criteria to insure the maintenance of fish populations in the streams transversed by the pipeline and adjacent roads (MacPhee and Watts, 1973).

Other Activities

The U.S. Soil Conservation Service has thousands of large and small projects in the Columbia River drainage. Many of these projects affect fish survival either directly or indirectly. The list is by no means complete, but it does demonstrate the significance of irrigation, flood control, and soil conservation on fish survival.

Recreational facilities can be created by damning or diverting water. Boating and fishing in lakes or ponds provide the public with many hours of relaxation. However, even these lesser diversions can at times affect fish populations adversely by creating the same conditions that are associated with the diversions outlined previously.

Industrial Water Supply Systems

Industry diverts large quantities of water from both saltwater and freshwater systems. This water, diverted for industrial purposes, can be altered physically, chemically, and thermally. The accumulation of heat and toxic pollutants which are related to industrial and domestic uses can directly, or indirectly through synergism, adversely affect the survival of fish populations. There are many major industrial intakes and outfalls on the Columbia River between Bonneville Dam and Astoria, Oreg.; the chemical input includes organic and inorganic solids, mercury, phenolic compounds, cyanides, fluorides, chlorine, sulfates, thiosulfates, organic phosphates, and acrolein (a slime controlling agent). Estimates of pollutants that enter the Columbia River from industrial and domestic diversion include some 1,800,000 pounds of total solids, including 20,000 pounds of fluorides and 25 pounds of mercury per day. The thermal input from these sources is estimated at 37,660 million Btu (British thermal units) per day during the summer months.[1]

DEVELOPMENT OF FUTURE WATER DIVERSIONS

Various proposals have been made for interbasin transfer of continental water to satisfy the steadily increasing demands for water in the densely populated and arid regions of the United States and Canada. The people of the southwestern United States would like to transfer water southward from the Columbia and Snake rivers of the Pacific Northwest. California has a program for moving water from three northern areas to the more arid south. The United Western Investigation, a project completed by the Bureau of Reclamation in 1951, proposed more

[1]Fulton, L. A. 1971. A preliminary report on types and locations of pollution outfalls on the lower Columbia River. Unpubl. manuscr., 22 p. Natl. Mar. Fish. Serv., NOAA, Seattle, Wash.

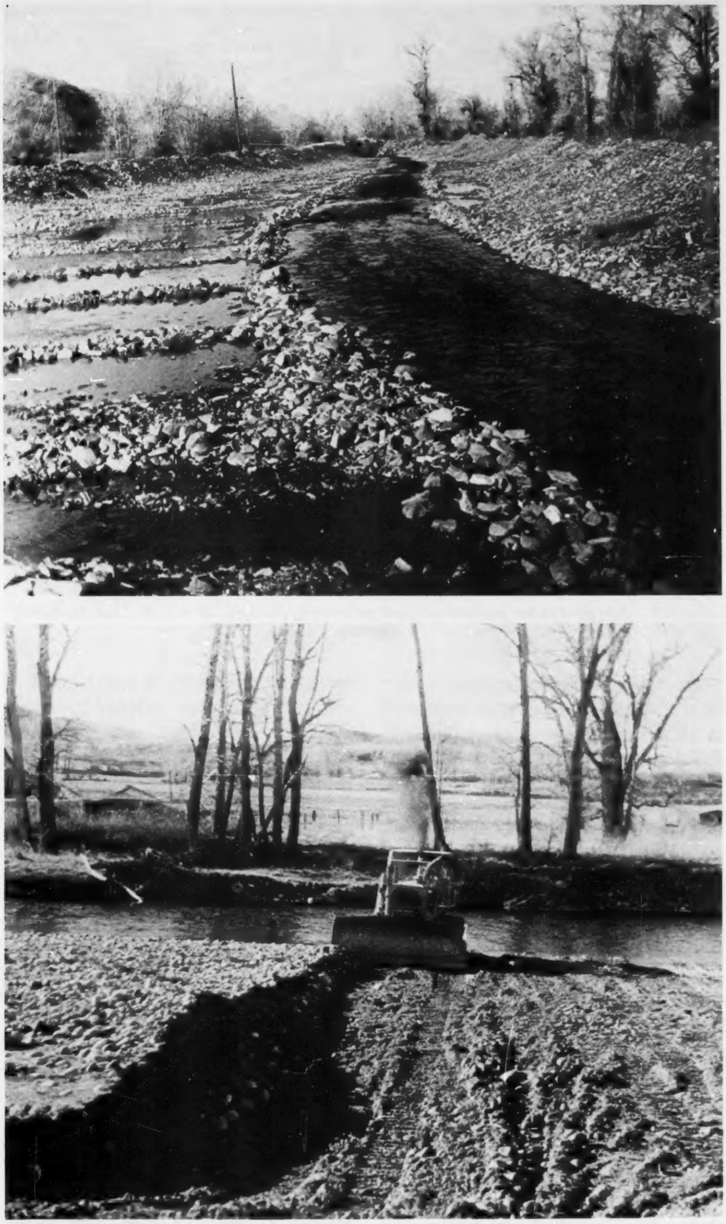

Figure 2.—Desecration of a stream bed associated with road construction.

than 30 different possibilities for diverting Pacific Northwest waters to the Southwest. More recently there has been a proposal which dwarfs those mentioned. This plan, the North American Water and Power Alliance (NAWAPA), or the "Parsons Plan," would cost $60-100 billion and take more than 30 years to complete (Parsons, 1964). It would bring water from the Yukon, MacKenzie, and other rivers of Canada and Alaska and carry it throughout the western states of the United States and provinces of Canada, providing vast regions with an abundance of water. It would even provide the northern provinces of Mexico with a water supply. It would connect the Peace and Fraser Rivers in British Columbia with the Great Lakes, and canals would be dug through the western provinces of Canada through which deep draft vessels might travel from ocean to ocean. Most concervationists have adopted the view that the transfer of water from northwestern North America would adversely affect fish populations in the area.

IMPACT OF WATER DIVERSION ACTIVITIES

Freshwater and Anadromous Fishes

Commercial and Recreational Fishery Resources

The impact of water diversions on local fishery resources has varied widely on the west coast. Generally, major water diversions are detrimental to native populations of fish, but some fishermen have benefitted by the construction of dams and the formation of reservoirs in areas that had little, if any, fishery resources. Weighing fishery losses against fishery gains, it is apparent that the losses in the Pacific Northwest have been much greater than the gains; valuable commercial and recreational fisheries for salmon and steelhead trout, for example, have been detrimentally affected in the Columbia River system by water diversions. In the arid Southwest, on the other hand, there has been a considerable increase in fish habitat and recreational fishery resources because of water-storage reservoirs.

In the Columbia River, estimates of mortality of juvenile salmon and steelhead trout in any one year are as high as 70-90 percent during their seaward migration (Cleaver, 1969; Pacific Northwest River Basins Commission, 1974). Most of this mortality could be directly or indirectly related to man's diversion of the river system. We have tried to compensate for these losses by hatchery production, but hatchery reared fish are subjected to the same detrimental conditions as are the naturally spawned individuals. Approximately 500,000,000 juvenile salmon and trout migrate seaward in the

Columbia River each year, more than half of which are hatchery reared. Water which is diverted from a stream or river to supply a fish hatchery can be returned to the system with detrimentally altered water quality, thus adding to the complexity of the overall problem.

Rare and Endangered Species

It has been established that there is an adverse effect on some fish populations caused, in part, by large and small water diversions. It is virtually impossible to quantify the losses; as the population increases, the problem will become more severe. Already we have several groups of fishes on the Rare and Endangered Species List of the U.S. Fish and Wildlife Service (1973) as a direct and indirect result of water diversion. While most of the fish on the list are not important in commercial or recreational fisheries, we may one day find important species included.

Figure 3.—A type of under-road culvert used extensively during construction of the Alaska oil pipeline.

Marine Fishes and the Marine Environment

To this point, we have discussed the impact of water diversion on freshwater and anadromous species rather than on marine fishes. Marine species that inhabit the estuary during all or a part of their life cycles can also be adversely affected by changes in that environment. Water quality and physical conditions can be altered by water diversions in rivers and streams flowing into the estuary. An obvious interaction between diversion structures and the estuary is an overall reduction in quantity and cycles of flow. For example, water impoundment in some rivers has virtually eliminated spring runoffs, while later summer low flows have altered natural physical and chemical patterns in the estuaries. Small diversion structures, such as dams, dikes, weirs, and locks, appear innocuous. Yet even one of these structures on a stream tributary to an estuary can have profound effects on salinity levels and current patterns. These types of changes can upset the ecological balance of an area far out of proportion to the size of the diversion structure. Though these small structures (along with their large counterparts, the high dams and large impoundments) can be above tide water, their influence is as important as that of structures within the estuarine or coastal zones themselves (DeGuerrero, 1970).

Estuarine fish populations (and secondary food organisms) are affected by the discharges of industrial and domestic diversions which are returned to the system untreated. Studies have shown that sulfite pulp-mill wastes are harmful in several ways: 1) they may be injurious to migrating salmon and steelhead trout, 2) they may suppress phytoplankton and zooplankton activity in the harbor, 3) they may inflict direct damage to eggs and larvae of marine species, and 4) they may create sludge deposits which are detrimental to bottom organisms on which fish rely for food. The pulp and paper industry has many water diversions that return sulfite wastes to the estuary of Washington's Puget Sound—which covers about 883 square miles and supports many populations of anadromous and marine species. In San Francisco Bay, the estuarine communities have not only been reduced in species composition but also in number of individuals, presumably through the effect of toxic wastes (Warren, 1971).

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MFR PAPER 1224

Concluding Remarks

MAURICE E. STANSBY

Many types of situations adversely affecting aquatic biota in the region bordering the northeastern Pacific Ocean may already be of a serious nature, if not in the future. In considering these matters here in a preliminary way, we can divide such problems into two categories: 1) those based upon physical changes; and 2) those arising as a result of chemical action.

Under physical types of activities causing potential problems are two industrial activities of great importance to the region under consideration. Diversion of waters has already been carried out to a greater extent here than in any other part of the country. We can certainly see that such activity has, even during the past several decades, resulted in very serious inroads into anadromous species of fish, especially salmon. A second physical type of alteration is the change in water temperature brought about by using water as a means for cooling in industrial operations. Such a change is, of course, of greatest concern for installations located either on rivers and streams or on enclosed marine bodies of water. Where volumes of water available to serve as the coolant are restricted, a considerable rise in temperature of water can occur. The use of water as a coolant will, in all probability, increase tremendously in the next few decades in connection with the installation of thermonuclear electrical generating plants. With a preponderance of electrical power having been generated in northwestern North America by hydroelectric means in the past, the problems connected with raising water temperatures from electric power developments have been of less significance in this region than elsewhere in the country. They will, however, certainly become a major consideration in the near future.

Potential problems based upon chemical activity of pollutants entering waters can stem from a variety of sources including discharge of effluents from chemical manufacturing operations, uses of chemicals which may get into waters either from general industrial or agricultural and lumbering operations, discharge of raw or partially processed municipal sewage into waters, and accidental spillage of raw materials or chemicals during transport. These are the chief ways in which this class of pollutant can become problematical.

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In the past, because the regions bordering the northeastern Pacific Ocean have had much lower population and less industrial and agricultural activity than most other areas of the country, these types of problems have, for the most part, been much less severe. In the future, buildup of populations and industry in the northwestern part of North America will increase such hazards. Especially, changing patterns in certain industrial operations such as the recent petroleum operations in Alaska could intensify these problems very rapidly in the near future.

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Space Technology Aids Fisheries Research

A team of fishermen, engineers, physicists, oceanographers, biologists, and computer specialists have "found" fish with a satellite in a unique experiment off the Louisiana coast. The project represents the culmination of a larger effort — the LANDSAT Menhaden and Thread Herring Investigation—initiated last year by the National Oceanic and Atmospheric Administration (NOAA).

Investigating the feasibility of using satellite data for assessing fisheries resources in the northern Gulf of Mexico, and thereby enhancing management of them, has been a cooperative industry-Federal Government project. Personnel from the Earth Resources Laboratory of the National Aeronautics and Space Administration and the Southeast Fisheries Center of NOAA's National Marine Fisheries Service have been working together with boats, planes, and crews from member companies of the National Fish Meal and Oil Association.

Their work has shown that there are relationships between the distribution of menhaden and water turbidity, which the LANDSAT sensor measures as water color. From the water colorations sensed by LANDSAT, scientists can infer the probable presence or absence of menhaden. The satellite cannot sense, or "see" fish directly.

Menhaden vessels, fishing under the direction of their spotter aircraft pilots, confirmed the presence of menhaden in most, though not all, of the high probability concentration areas predicted by analysis of LANDSAT data, while special navigation systems plotted the locations of the fish precisely and scientific observers on board several vessels collected water samples.

Thus, they validated a technique for locating fish concentrations from space which may lead to a greatly improved understanding of coastal fishery ecology and to better methods for resource assessment and management.

The analysis of LANDSAT data in near "realtime" began when LANDSAT I passed over the selected study area in the late morning hours of 19 July 1976, sending electromagnetic multispectral scanner data to a receiving station at the Goddard Space Flight Center in Greenbelt, Md.

At the receiving station, investigators reviewed the data prior to storing it on four large magnetic tapes. The tapes were then hand-carried to the NASA Earth Resources Laboratory in Slidell, La., where another team of scientists further processed the satellite's information, geographically referenced it, and analyzed it for high probability menhaden areas. At approximately 7:15 a.m. on 20 July, less than 21 hours after the satellite began viewing the study area, the first telephone calls were made to inform spotter pilots and vessel captains of the probable locations for menhaden so that they could compare and check their vessel findings with the scientific predictions as an experimental control. Early reports from the fishing industry indicate that the satellite did its job well.

While the test was a success, considerably more work will be required before an operational satellite system can be made available for application to fishery problems. At best it will take three to five years before such a system could become operational. Other coastal, and perhaps oceanic, species will have to be considered and additional investigations may be required. Special computer programs and facilities will have to be developed. The concept, however, has been demonstrated and that should make future efforts easier.

NOAA Researchers Track Tagged Skipjack Tuna

A cooperative undertaking between the Hawaiian fishing boat *Anela* and the NOAA research vessel *Townsend Cromwell* paid off well last summer with additional information being collected on the swimming patterns of Hawaii's large, "season" skipjack tuna. The *Cromwell* is presently assigned to the Honolulu Laboratory of NOAA's National Marine Fisheries Service, an agency of the Department of Commerce.

Laboratory Director Richard Shomura explained that the *Anela* and the *Cromwell* teamed up to catch, tag, release, and follow four large aku on what was otherwise a routine fishing trip for the *Anela*. When she fished schools of large (12 kg) skipjack to the north of Oahu just off Kahuku, a NMFS observer aboard tagged four of the fish by inducing each to swallow a small, pressure-sensitive sonic tag.

The fish were released and the *Cromwell*, using sonar equipment, followed each by following the sounds emitted by the tags, beeping sounds that varied in frequency with pressure. The deeper a tagged fish swam, the greater the pressure on its tag and the faster the beeps.

According to Shomura, this successful tagging experiment will help Laboratory fishery scientists understand the possible habitat limitations placed on the skipjack by its own ability to conserve body heat. Previous Laboratory research into the physiology of skipjack tuna showed the muscle temperature of a 13 kg (39 lb) fish to be as much as 15°C above the surrounding water temperature. Lengthy exposure to water over 20°C, it has been hypothesized, is avoided by large aku because an internal temperature of 35°C causes irreversible muscle damage.

Information gathered from this experiment can also aid the local commercial fishermen, Shomura continued. Knowing when fish are at the surface can result in adjustments in fishing strategy and in turn to more effective fishing trips, he said.

NMFS HELPS FUND SALMON HATCHERY

A grant of $225,950 to complete construction of the Humptulips Salmon Hatchery near Grays Harbor, Wash., has been awarded to the Washington Department of Fisheries by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service.

The award, funded under the Anadromous Fish Conservation Act, is

based on a State-Federal cost sharing basis of 72/28 percent. Previous Federal grants totaling $670,950 have been made during the past two years by the Department of Commerce. The State of Washington's share of the cost has been $2,309,800, for a total cost of $3,206,700 for the project.

The hatchery, started in 1973, is scheduled to be completed and in operation late this year. The project includes incubation facilities, rearing pens, a water distribution system, an intake pump station, fish ladder, and settling ponds.

Projections of returns of fish raised and released by the hatchery should add approximately $700,000 annually to the salmon fishery in the state. The hatchery will be operated by the Washington Department of Fisheries.

Cannon Named Fisheries Conservation Coordinator

Kessler R. Cannon has been named to the post of Conservation Coordinator of the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, NMFS Director Robert W. Schoning announced late last summer.

Cannon, for seven years Assistant to Governor Tom McCall of Oregon for natural resource and environmental affairs, will have primary responsibility for conservation relations for the agency at the national level, working closely with the environmental community on matters of mutual concern. NOAA is an agency of the U.S. Department of Commerce.

Cannon

"I'm especially pleased to have someone with Mr. Cannon's experience to work with regional and national conservation groups," Schoning said. "His job is to ensure that the NMFS is aware of the concerns of environmentalists and conservation organizations, and that they in turn know about our efforts in the entire range of conservation of our marine resources."

Cannon, who began his new assignment 21 July, is a native of Oregon, and during the past year served as an Oregon State University professor, teaching natural resource and environmental management. He is a graduate of the University of Oregon.

Hawaiian Monk Seal Called Endangered

The Hawaiian monk seal is in danger of becoming extinct and may be placed on the endangered species list, according to a proposed ruling by Robert W. Schoning, Director of the National Marine Fisheries Service, and Lynn A. Greenwalt, Director of the U.S. Fish and Wildlife Service. The proposed rulemaking that would list and protect the Hawaiian monk seal (*Monachus schauinslandi*) as an endangered species throughout its range is issued under the authority of the Endangered Species Act of 1973.

Found throughout the Hawaiian Archipelago, the Hawaiian monk seal breeds only on the islands of the Leeward Chain, including French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway Atoll, and Kure Atoll. A status review undertaken by the NMFS, a Department of Commerce agency, reflects the rarity of the species, the high mortality in pups, the relatively low reproductive rate, and indications of population decline and harrassment. The Marine Mammal Commission and its Committee of Scientific Advisors agree with the NMFS status review and recommend that the species be listed as endangered.

Research efforts since December 1975 by NMFS in cooperation with the U.S. Fish and Wildlife Service are outlined in a preliminary document released in May 1976 by the Northwest Fisheries Center, an NMFS branch. The report includes the count of recent beach and shipboard surveys of this species. NMFS believes this information clearly indicates the Hawaiian monk seal is presently in danger of extinction and supports a proposed endangered status. As a further reflection of concern over the viability of this species, the NMFS recently classified the Hawaiian monk seal as depleted under the Marine Mammal Protection Act of 1972. However, it is believed that by listing the seal as endangered, a higher level of protection may be afforded the animal and its habitat.

NOAA Buoys Set in East Pacific, Gulf of Alaska

The National Oceanic and Atmospheric Administration (NOAA) has deployed five huge deep-ocean environmental data buoys off the northwest coast of the United States and the Gulf of Alaska during the summer.

The 55-ton buoys were built by the General Dynamics Corporation, San Diego, Calif., under contract to the Commerce Department agency. Developed by NOAA's Data Buoy Office, a component of the National Ocean Survey, the buoys will serve as a prime source of data for weather prediction and storm warnings from areas where data is sparse and storms are known to develop.

The environmental buoys are the product of a five-year program to develop an operational buoy with high reliability, low life-cycle costs, a sensor system of above average accuracy, and efficient maintenance at sea. A prototype has been operating successfully 344 nautical miles southwest of Astoria, Oreg., since July 1975.

The buoys have discus-shaped hulls, 33 feet in diameter, and are capable of surviving 155-knot winds and 50-foot high waves. They are powered by air-depolarized batteries, sufficient for three years of operation.

Data from the buoys is transmitted routinely every three hours—every hour in critical storm conditions—via high frequency or satellite communications to shore collection stations in San Francisco, Calif., Miami, Fla., and Wallops Island, Va. It is then forwarded to the National Weather Service to be incorporated into marine weather reports.

Meteorological data reported will include wind speed and direction, air temperature, and barometric pressure. These measurements are made by sensors on the buoy mast, 10 meters above the sea surface. All instruments except those measuring air tempera-

ture have back-up systems for added reliability.

Oceanographic data reported will include surface seawater temperature, subsurface temperature measured at six depths from 10 to 300 meters, and one-dimensional spectral wave data.

Deployment sites range from 41° North to 56° North and from 131° West to 156° West. The buoys are moored in water depths from 9,300 to 15,500 feet.

FILM ON ESTUARIES RELEASED BY NOAA

"Estuary," a 28-minute, 16-mm color film on the estuarine areas of the United States—upon which much of our seafood is dependent—has been released by the National Oceanic and Atmospheric Administration (NOAA). Produced by NOAA and sponsored by the Environmental Protection Agency, the film depicts industrial uses of estuaries, and also shows their importance as a principal source of food, a breeding place for fish and wildlife, and a site for recreation.

Any human action taken in an estuary is likely to have a series of important reactions, the film stresses, pointing out the need for wise management. Estuarine areas depicted are Maryland's Chesapeake Bay, Florida's Tampa Bay, California's San Francisco Bay, and Oregon's Coos Bay.

Of interest to anyone concerned with the environment, "Estuary" is aimed at general audiences but is appropriate for science and ecology classes in educational institutions of all levels. The film was produced under contract, using personnel and facilities of Hal Kirn Associates of Washington, D.C., and was supervised by Elliot Macklow, Chief, NOAA Motion Picture Services. It has an original score by William Penn and is narrated by Mel Brandt.

NOAA also has two other films dealing with estuaries in distribution; "Estuarine Heritage," and "The Biologist and the Boy," which is theatrically distributed as "Crisis in the Coast." Prints are available on loan, free of charge, from NOAA Motion Picture Service, ESTUARY, 12231 Wilkins Ave., Rockville, MD 20852, telephone (301) 443-8411. A catalogue listing all NOAA films is available at the same address.

United States, Japan Research Albacore

Research by the United States and Japan on the North Pacific albacore stock—thought to be approaching its biological limits—will be continued under an informal agreement announced late last summer by the National Oceanic and Atmospheric Administration (NOAA).

In recent years the total annual harvest of North Pacific albacore has increased from 70,000 to 100,000 metric tons, primarily because of the expansion of the Japanese pole-and-line fishery, which accounted for 64 percent of the 1974 catch. Other major fisheries are the Japanese longline, 15 percent; and the U.S. troll and live-bait fisheries, 21 percent.

The agreement between the two nations emerged from a population dynamics albacore workshop held at NOAA's National Marine Fisheries Service laboratory in Honolulu, Hawaii, in December 1975, and involved the NMFS' Southwest Fisheries Center, La Jolla, Calif., and the Far Seas Fisheries Laboratory, Shimizu, Japan.

The Commerce Department agency's workshop considered preliminary stock assessments based on standard analyses of catch, effort, and size composition that put the maximum sustainable annual yield for albacore between 115,000-125,000 metric tons, only slightly above the current catch.

The on-going investigation includes participants from the California Department of Fish and Game, the Oregon Department of Fish and Wildlife, the Washington Department of Fisheries, and the Pacific Marine Fisheries Commission.

United States albacore fishermen actively support and finance government-industry research programs with the objectives of increasing the efficiency of albacore fishing and developing scientific information for albacore conservation.

Foreign Fishery Developments

New Zealand Asks Foreign Fishing Vessel Tax, 200-Mile Economic Zone Declaration

The New Zealand Government's annual budget message, released in Wellington on 29 July 1976, proposed a tax of from NZ$1,000 to NZ$5,000 on foreign fishing vessels entering New Zealand ports (NZ$1.001 = US$1.00). The exact amount of the tax will be based on the size of the vessel. In a press conference on 30 July, Prime Minister Muldoon explained that the tax is an example of his Government's determination to win access to foreign markets for New Zealand farm products and is intended to put present and potential foreign fishermen on notice that New Zealand insists on some economic benefit from the exploitation of its marine resources.

The Prime Minister also announced that draft legislation was being prepared to declare a 200-mile exclusive economic zone in the event of unsatisfactory progress at the Law of the Sea Conference, then meeting in New York. New Zealand plans to coordinate such a declaration with Australia and other independent Pacific island countries of the region. (Source: American Embassy, Wellington, New Zealand.)

According to the NMFS Office of International Fisheries, New Zealand would acquire an area of seabed totalling 1,409,500 square nautical miles if the Government extends national jurisdiction to 200 nautical miles. The superjacent waters contain tuna, squid, and other commercially valuable fish. Both Japan and the Soviet Union have engaged in fishing operations in waters near New Zealand for many years. Fishing vessels from Taiwan entered the grounds in 1974. The vessels from the Republic of Korea also fish there.

Japanese interest in marine resources in waters near New Zealand dates from the 1950's. At that time, tuna was the major target species and much effort was exploratory in nature. Growing Japanese presence in nearby waters led New Zealand to declare 12-mile fishery limits in 1967 and to

begin a phase-out of Japanese fishing inside the limits. The two countries signed a bilateral fishery agreement on 12 July 1967.

Following the legal developments, Japanese fishing companies began to set up joint ventures with New Zealand partners. Taiyo Gyogyo and its New Zealand partner established Tamouna Fisheries Ltd. in 1967. Hokuyo Suisan, C. Itoh, and a New Zealand firm established Sealord Development Ltd., in 1971. Kyokuyo Suisan and the New Zealand company P. Feron and Sons jointly conducted a tuna survey in 1972, and this was followed in 1973 by the establishment of Jaybel Inc., a joint venture between Nichimo Co. and J.B.L. Seafood Corp. of New Zealand.

The squid resource in New Zealand waters first attracted Japanese attention as suitable baitfish for tuna longliners, but Japanese resource surveys demonstrated the commercial potential of catches for human consumption. The *Hoyo Maru*, a Japanese research vessel, surveyed the squid resource in 1970 and discovered commercial quantities of broad-finned squid. By 1972, Japan had 73 squid vessels in waters near New Zealand taking 13,800 metric tons of squid. In 1974, 151 vessels caught about 18,400 metric tons.

In addition to tuna and squid, approximately 16 other species of fish are taken from waters near New Zealand by Japanese fishing vessels. Among these, sharks, jack mackerel, and tarahiki (*Cheilodactylus macroperus*) are the more important species. Other species include crab, trevally, snapper, sea breams, red gurnard, soles, flounder, cod, barracudas, dories, mullet, pilchard, and sprat. Some of these demersal fish are processed into meal and into surimi, a minced fish meat product. In 1971, Wonder Foods, Inc. of New Zealand, Hokuyo Suisan and C. Itoh Co. established a surimi operation in New Zealand. The effect of the proposed tax on foreign fishing vessels on Japanese investment in New Zealand and on the level of effort in nearby waters would be significant.

According to the Japanese press, the announcement of New Zealand's new tax on foreign fishing vessels took Japan's Fisheries Agency by surprise and is causing serious concern among Japanese tuna and squid fishermen who have been operating in waters near New Zealand. In the past, foreign fishing vessels have been allowed free entry into ports and Japanese port calls in New Zealand average 700 per year.

The Soviet Union began to expand its Pacific fisheries in the early 1960's when many new vessels, built in both domestic and foreign shipyards, joined the Soviet Far Eastern Fishing Fleet.

The thrust of the Soviet expansion was first in the Bering Sea and the Gulf of Alaska, where the Soviet Pacific Institute for Fisheries and Oceanography (TINRO) conducted extensive exploratory fisheries research during 1954-58. In 1959, large-scale Soviet fishing began in that region and soon expanded southward off Oregon, Washington, and California.

By 1965, the TINRO scientists began to plan a second major exploratory fisheries expedition, this time to the South Pacific and Indian Ocean waters. The expedition (called the "*Lira* Expedition" after the leading research vessel), in which one to two dozen TINRO vessels participated, lasted several years (1966-68) and gave Soviet fishery scientists a good idea where the South Pacific fishery resources are concentrated. Special attention was paid to the enormous expanse of the continental shelf off Australia and New Zealand. Since most TINRO vessels taking part in the *Lira* Expedition were basically commercial fishing vessels, it can be said that Soviet fishing off New Zealand dates from 1966.

In early 1967, New Zealand extended its fishery limits to 12 miles to counter the pre-emption of traditional coastal fishing grounds by Japanese and Soviet fishermen. A few months later, Australia also extended its fisheries jurisdiction to 12 miles for the same reason.

In May 1967, the New Zealand Government began negotiations with the Japanese and after arduous discussions, during which Japan threatened to take New Zealand before the International Court of Justice, allowed the Japanese fishermen to fish inside newly-proclaimed 12-mile fishing limits until a phase-out in the future.

The Soviet Embassy in Wellington was keeping abreast of these developments and a Soviet diplomat (Shliapnikov) publicly assured New Zealanders that a severe "warning" was issued to Soviet fishing captains not to transgress the 12-mile limits. At the same time, the Soviet diplomat expressed the desire to have the same privilege as the Japanese fishermen, namely to fish inside the 12-mile limit until Japan's phase-out ended. The Soviet request raised eyebrows in New Zealand fishing industry circles, but, as far as is known, the New Zealand Government did not allow the Soviets the same privileges it accorded the Japanese.

Nevertheless, New Zealand ports remained open to Soviet commercial and exploratory fishing vessels for needed supplies (water, fuel, provisions) and repairs. Since Soviet Pacific fishery logistics during the late 1960's were overextended, this was an important concession on the part of New Zealand.

By July 1972, as many as 10 large Soviet stern factory trawlers fished off New Zealand and the General Manager of the New Zealand Fishing Industry Board called at a fishermen's conference for 75-mile fishery limits. Soviet fishing off New Zealand has continued uninterrupted since 1972. No information on Soviet catches was given to the New Zealand Government or its biologists despite repeated Soviet promises to do so. In 1974, the Soviets were publicly chided for their lack of cooperation in providing catch statistics.

Faced with increasing fishing pressures by the Soviet, Japanese, and lately, also Taiwanese and South Korean fishermen, the New Zealand fishing industry escalated its responses. In December 1975, Wellington fishermen picketed a pier where Soviet fishery supply vessels were anchored. Demands for the extension of fishery limits to 200 miles also continued to escalate.

When the Labor Government was defeated in recent elections, the Government formed by Muldoon was much more responsive to fishermen's demands. On 17 May 1976, Prime Minister Muldoon expressed concern over Soviet attempts to establish a fisheries base on the island of Tonga or on other South Pacific islands nations and referred to "40 Soviet vessels fishing in our waters". The Govern-

ment also began to collect and publish data on calls of foreign fishery vessels in New Zealand ports (230 vessels called from January to March 1976 alone). (Sources: New Zealand and Japanese press reports; *World Fishing; Ocean Fisheries,* and others.)

CANADA-SPAIN SIGN FISHERIES AGREEMENT

Canadian and Spanish representatives met in Madrid on 10 June 1976 to sign a bilateral fisheries agreement. The agreement establishes the terms and conditions governing continued fishing by the Spanish fleet off Canada's Atlantic coast. The Canadian delegation was led by L. H. J. Legault, Director-General, International Fisheries and Marine Directorate. The Spanish delegation was led by Victor Moro Rodriguez, Director-General of Fisheries, Ministry of Commerce. Negotiations leading to the agreement took place in Ottawa earlier in the year. The agreement went into force on 18 June 1976.

The agreement allows Spain to fish in Canadian Atlantic coastal waters, taking into account the anticipated legal and jurisdictional changes in Canadian fisheries limits. Canada will determine catch allocations annually for Spanish vessels based on the total allowable catches of fish stocks, Canada's harvesting capacity, the surplus stocks available, and Spain's traditional fishery off the Canadian east coast. Spanish vessels must obtain licenses to fish in Canadian waters, and will be allowed port privileges to obtain supplies. Spain has agreed not to fish anadromous stocks which originate in Canada.

The agreement also provides for further bilateral discussions to increase cooperation in the exchange of technical information, improvement of processing and utilization of catches, and the reduction or elimination of tariff barriers for fishery products originating in Canada. The present agreement shall be subject to review by the two governments after a period of two years or at any time following the ratification of a future multilateral convention dealing with the same matters. The agreement may be terminated by either party 10 years after the date of its entry into force, although 12-months notice must be given to cancel.

According to the NMFS Office of International Fisheries, the agreement is the latest in a series of Canadian bilateral fisheries agreements. Agreements have recently been signed with the USSR, Poland, and Norway. Portugal is expected to conclude a similar agreement soon. The terms of the signed agreements differ only slightly. Polish and Soviet fishing fleets are allowed to operate off both Canada's Atlantic and Pacific coasts, and the agreements signed by Norway, Poland, and the USSR remain in force 6 years, in contrast to Spain's 10-year agreement. (Source: U.S. Embassy, Ottawa.)

Indian Parliament Takes EEZ Reins

India's Minister of Parliamentary Affairs introduced constitutional amendment in Parliament on 21 May 1976, providing that the demarcation of territorial waters, the continental shelf, and such other maritime zones of India as the exclusive economic zone, shall be made by India's Parliament. As India is a Union of States, the word "Union" refers to India's central government. The following is the text of the amendment:

"Article 297. (1) All lands, minerals and other things of value underlying the ocean within the territorial waters or the continental shelf, or the exclusive economic zone of India shall vest in the Union and be held for the purposes of the Union.

"(2) All other resources of the exclusive economic zone of India shall also vest in the Union and be held for the purposes of the Union.

"(3) The limits of the territorial waters, the continental shelf, the exclusive economic zone and other maritime zones of India shall be such as may be specified, from time to time, by or under any law made by Parliament."

Formerly, the words "exclusive economic zone" were not included in the Article. Before the passage of the amendment on 26 May 1976, the limits of India's territorial waters and the continental shelf were determined by a proclamation issued by the Indian President. The new law now states that such maritime limits will be determined by the Indian Parliament.

According to the NMFS Office of International Fisheries, India claims a 12-mile territorial limit and a 12-mile fisheries jurisdiction, but reserves the right to declare a 100-mile fishery conservation zone. Maritime limits between India and Sri Lanka were earlier resolved through bilateral discussions described in a 3 May 1976, release titled "India and Sri Lanka Agree on Boundaries." (Source: U.S. Embassy, New Delhi.)

World Fishery Developments Noted

The Division of International Fisheries Analysis, which follows trends in world fisheries for the National Marine Fisheries Service (NMFS) has prepared the following summary of the recent significant developments in world fisheries.

The Faeroe Islands will extend its fisheries jurisdiction to 200 miles by 1 January 1977, it was announced by Danish Prime Minister Jorgensen. The Faeroe Islands Parliament passed a resolution of 6 August calling for the Danish Government to extend Faeroese fisheries jurisdiction.

Mozambique's cabinet has approved a decree establishing a territorial sea of 12 nautical miles and an economic zone of 200 nautical miles.

Icelandic fishery exports during the first four months of 1976 were 109,000 metric tons valued at $77.6 million, compared with 107,000 metric tons valued at $71.0 million exported during the same four months in 1975. The United States imported more than one-third of this amount, or approximately $29 million worth of fishery products.

Mexico is increasing its capability to patrol the newly-established 200-mile Exclusive Economic Zone. The Government bought several patrol vessels in the United Kingdom, and is now constructing the same class (*Azteca*) in domestic shipyards. At the same time, Mexican Navy officials are thinking about equipping patrol units with long-range radar.

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